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## Final Report

### Geomorphology & Sediment Source Assessment Technical Memorandum

### Aptos Creek Watershed Assessment



*submitted to*

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*by*

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## 1.0 – INTRODUCTION

### 1.1 – PROBLEM STATEMENT

The Aptos Creek Watershed historically supported healthy runs of both steelhead trout (*Oncorhynchus mykiss*) and coho salmon (*Oncorhynchus kisutch*). Due to impacts, such as loss of watershed continuity (i.e. -barriers), excessive fine sediment loads, reduction in streamflow, degradation of water quality, modification to the coastal lagoon, and loss of channel complexity (e.g. – loss of floodplains, removal of woody material), the population of these species have declined, or in the case of coho salmon, been lost completely. Recent fisheries assessments of perennial streams within the watershed suggest that sufficient habitat exists to support both steelhead and coho. Both species have been listed under the Federal Endangered Species Act and targeted for restoration in Aptos Creek.

Impairment of rearing habitat and loss of pool depth due to deposition of fine-grained sediment is seen as a major contributing factor to reductions in steelhead and coho salmon populations in the watersheds draining the northern portion of Monterey Bay (San Lorenzo River, Soquel Creek, Aptos Creek; Swanson and Dvorsky, 2001; Alley, 2002; Dvorsky, Alley, and Smith, 2002). There are a variety of erosional processes that contribute sediment to stream channels, including landsliding, slumping, rilling, debris flows, and bank failures. Each process differs by the quantity, timing and grain size of sediment delivered to stream channels that may act as impairing sediment to salmonid production and rearing. Each process can also be classified into sources that are natural and those that are a result of human land use impacts. Erosion sources can also be classified into those that are episodic and those that are chronic. Based on results of the Zayante Area Sediment Study (Swanson and Dvorsky, 2001), it was found that chronic, fine sediment sources were the most impairing to aquatic systems and in most cases, the most cost-effective and feasible sources to treat.

Once sediment reaches the channel, hydraulic conditions and channel geometry dictate the way delivered sediment is routed and sorted through the system. Stream reaches are often classified by their width to depth ratio and slope characteristics (Rosgen, 1994), which are variables that can be used to determine their competence to move sediment of different sizes. Human-induced changes to stream valleys can have a significant impact on channel function, especially when those impacts occur within the inner gorge of the stream valley. Road development along a stream corridor can have a significant impact on channel function by straightening and narrowing of the channel and encouraging the removal of woody material. Narrowing and straightening of channels causes a reduction in hydraulic complexity that can limit sorting of fine sediment from coarser sediment and can reduce creation of important spawning and rearing habitat. Additionally, narrowing of the active channel can result in channel downcutting, accelerated stream bank erosion and subsequent removal of floodplain sediments that end up being deposited in the lower reaches of the watershed where the hydraulic forces are not enough to transport delivered sediment.

Many factors influence the eventual deposition of fine sediment in pools and spawning beds, including the quantity of material eroding from the hillslope, the adjacency of these sources to stream channels, the grain size of the sediment supplied, and the ability of the stream channels to transport, store, and sort the delivered sediment load. In this technical memorandum, we will discuss the methods and results used to assess and quantify erosion sources and channel conditions in the Aptos Creek Watershed, and the potential impacts these sources have on steelhead populations. Our research approach aimed to take a comprehensive look at sediment sources and the depositional environment in the stream channels that both

cause the erosion and limit natural movement of sediment through the system through hydraulic variability and properly functioning geomorphic conditions.

## **1.2 - BACKGROUND**

The Aptos Creek Watershed encompasses approximately 25 square miles of coastal land in southern Santa Cruz County, consisting of several major subwatersheds including Aptos Creek, Bridge Creek, Trout Gulch, Valencia Creek and Mangels Gulch (Figure 1). Approximately 60% of the watershed occurs within California State Parks property as the Forest of Nisene Marks, encompassing a large majority of Aptos and Bridge Creek subwatersheds. The remaining 40% of the watershed occurs on private land, consisting of a mix of forested, rural residential, suburban, and urban land in the Trout, Valencia, and Mangels subwatersheds.




### **1.2.1 – Geology**

The geology of the Aptos Creek Watershed is dominated by the presence of the northwest-trending San Andreas Fault, a transverse fault that is characterized by lateral movement of the North American and Pacific Plates. The San Andreas Fault and associated Rosalia Ridge skirts the northeastern boundary of the watershed (Figure 2). The San Andreas Fault is considered to be very active in the study region, producing large magnitude seismic events, the most recent being the October 17, 1989 Loma Prieta earthquake. This 7.1 magnitude earthquake caused severe structural damage throughout the Bay Area and resulted in ground cracking and shallow landsliding throughout the Santa Cruz Mountains. The epicenter occurred within the Aptos Creek Watershed in the Forest of Nisene Marks State Park.





Other geologically important features include the Zayante Fault and the Glenwood Syncline. The Zayante Fault is thought to be an active fault system with seismic recurrence intervals on the order of 9,000 years (Petersen et. al., 1996). A recent magnitude 4.0 earthquake has been attributed to the Zayante Fault (Gallardo et. al., 1990). The Glenwood Syncline, which falls between the Zayante and San Andres fault system, is a dominant feature through Bridge Creek and upper Aptos Creek. The Glenwood Syncline appears to be consequent with a large portion of the landslides mapped in the Forest of Nisene Marks. Weber and Nolan (1992), based on a preliminary analysis of mapped landslides in relation to geologic units, suggested that that correspondence of the two features may either be a function of focused energy within the syncline, or may represent a general weakness of the rocks near the fold axis due to brittle deformation within the fold. Therefore, hillslope instability in this region is likely related to regional geologic structure, as well as the morphology of the valley (i.e. – hillslope angle, inner gorge) and the underlying rock type.

In terms of surface exposure of lithologic units, the Purisima Formation is the dominant rock type, comprising 62% of the entire watershed. By subwatershed, the Purisima occurs in 69% of Aptos Creek, 92% in Mangels, 82% in Trout, and 51% in Valencia (Table 1). The Purisima Formation consists of a sequence of siltstones and sandstones that were formed in a marine environment during the Pliocene (2-11 million years B.P.). Existing geologic maps of Santa Cruz County do not provide enough detail to differentiate distinct sequences within the Purisima. This information would be important when trying to define potential source areas of fine sediment. A significant proportion of the geologic units in the Aptos Creek Watershed consist of Quaternary deposits from the Pleistocene and Holocene (0-2 million years B.P.). Between 5 and 30 percent of the surficial geologic units are mapped as Quaternary deposits. In many cases, these relatively young deposits are unconsolidated and highly erodible when disturbed. They primarily occur within the Trout and Valencia Creek watersheds.

## Legend

-  Roads and Highways
-  Streams
-  Aptos Creek Watershed

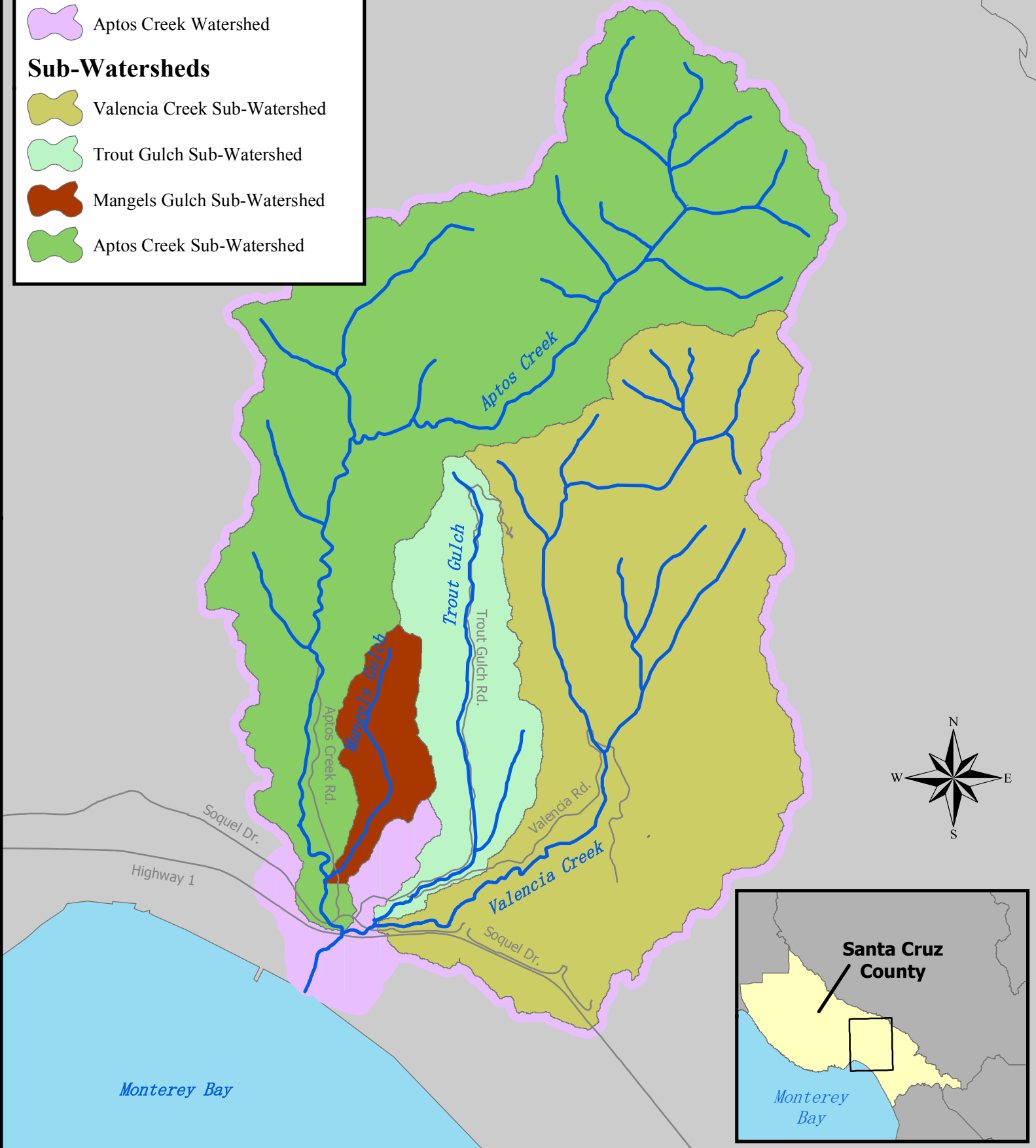
## Sub-Watersheds

-  Valencia Creek Sub-Watershed
-  Trout Gulch Sub-Watershed
-  Mangels Gulch Sub-Watershed
-  Aptos Creek Sub-Watershed

0 2,500 5,000 10,000

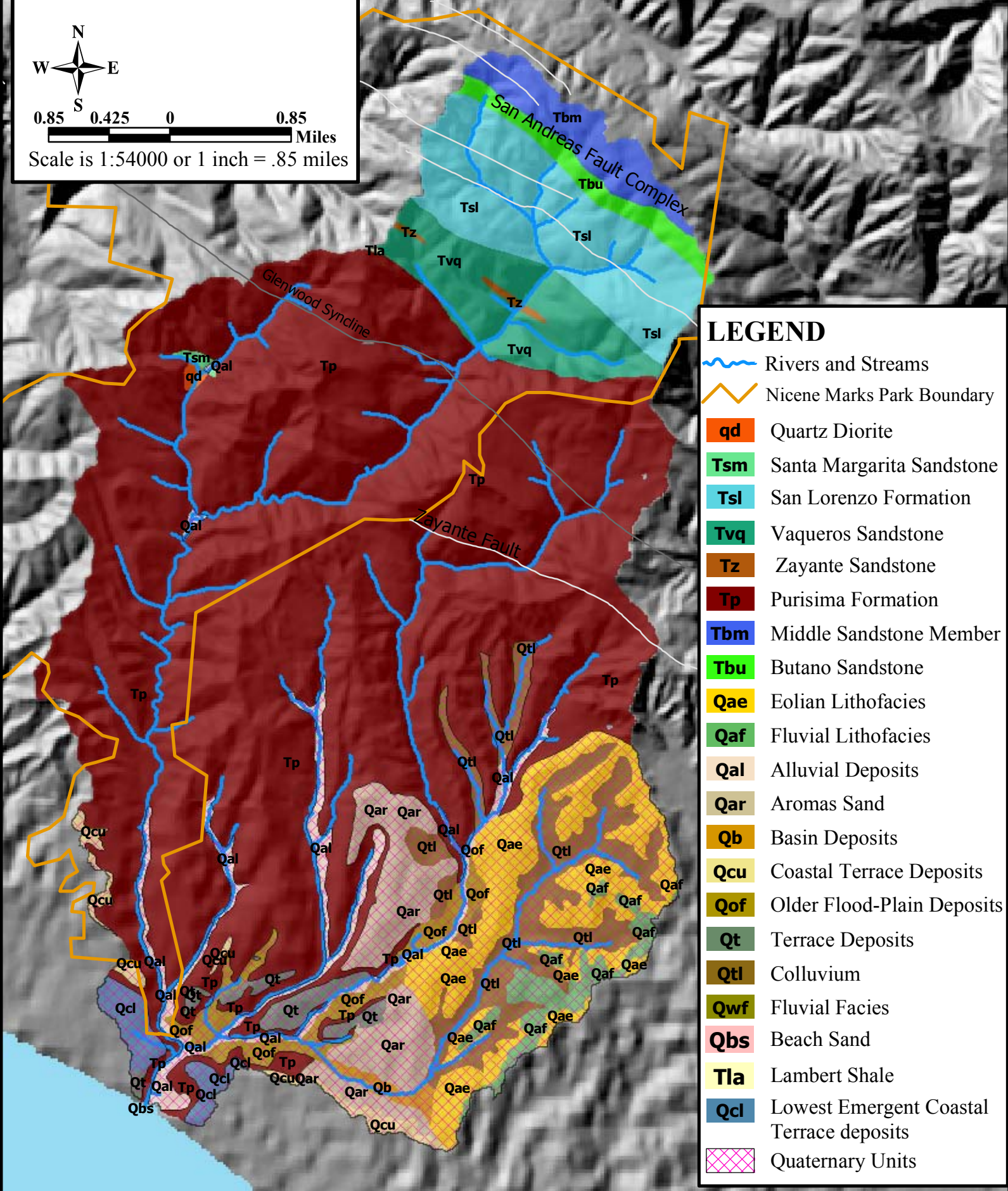
Feet

Scale is 1:60,000 or 1 inch = 5,000 feet





0.85 0.425 0 0.85 Miles  
Scale is 1:54000 or 1 inch = .85 miles



## LEGEND

- Rivers and Streams
- Nicene Marks Park Boundary
- qd** Quartz Diorite
- Tsm** Santa Margarita Sandstone
- Tsl** San Lorenzo Formation
- Tvq** Vaqueros Sandstone
- Tz** Zayante Sandstone
- Tp** Purisima Formation
- Tbm** Middle Sandstone Member
- Tbu** Butano Sandstone
- Qae** Eolian Lithofacies
- Qaf** Fluvial Lithofacies
- Qal** Alluvial Deposits
- Qar** Aromas Sand
- Qb** Basin Deposits
- Qcu** Coastal Terrace Deposits
- Qof** Older Flood-Plain Deposits
- Qt** Terrace Deposits
- Qtl** Colluvium
- Qwf** Fluvial Facies
- Qbs** Beach Sand
- Tla** Lambert Shale
- Qcl** Lowest Emergent Coastal Terrace deposits
- Quaternary Units

## Figure 2: Aptos Creek Watershed Assessment and Enhancement Plan

### Geologic Unit Descriptions

- Qae** Eolian lithofacies- Moderately well sorted eolian sand. Highly variable degree of consolidation owing to differential weathering. May be as much as 200 ft thick without intervening fluvial deposits. Several sequences may be present, separated by paleosols. Upper 10 to 20 ft of each dune sequence is oxidized and relatively indurated, with all primary structures destroyed by weathering. Lower part of each dune sequence below weathering zone may be essentially unconsolidated
- Qaf** Fluvial lithofacies- Semiconsolidated, heterogeneous, moderately to poorly sorted silty clay silt, sand, and gravel. Deposited by meandering and braided streams. Includes beds of relatively well sorted gravel ranging from 10 to 20 ft thick. Clay and silty clay layers, locally as much as 2 ft thick, occur in unit. Locally includes buried soils, high in expansive clays, as much as 14 ft thick
- Qal** Alluvial deposits, undifferentiated (Holocene)- Unconsolidated, heterogeneous, moderately sorted silt and sand containing discontinuous lenses of clay and silty clay. Locally includes large amounts of gravel. May include deposits equivalent to both younger (Qyf) and older (Qof) flood-plain deposits in areas where these were not differentiated. Thickness highly variable; may be more than 100 ft thick near coast
- Qar** Aromas Sand, undivided (Pleistocene)- Heterogeneous sequence of mainly eolian and fluvial sand, silt, clay, and gravel. Several angular unconformities present in unit, with older deposits more complexly jointed, folded, and faulted than younger deposits. Total thickness may be more than 800 ft. Locally divided into:
- Qb** Basin deposits (Holocene)- Unconsolidated, plastic, silty clay and clay rich in organic material. Locally contain interbedded thin layers of silt and silty sand. Deposited in a variety of environments including estuaries, lagoons, marsh-filled sloughs, flood basins, and lakes. Thickness highly variable; may be as much as 90 ft thick underlying some sloughs
- Qbs** Beach sand (Holocene)- Unconsolidated well-sorted sand. Local layers of pebbles and cobbles. Thin discontinuous lenses of silt relatively common in back-beach areas. Thickness variable, in part due to seasonal changes in wave energy; commonly less than 20 ft thick. May interfinger with either well-sorted dune sand or, where adjacent to coastal cliff, poorly-sorted colluvial deposits. Iron- and magnesium-rich heavy minerals locally from placers as much as 2 ft thick
- Qcl** Lowest emergent coastal terrace deposits (Pleistocene)- Semiconsolidated, generally well-sorted sand with a few thin, relatively continuous layers of gravel. Deposited in nearshore high-energy marine environment. Grades upward into eolian deposits of Manresa Beach in southern part of county. Thickness variable; maximum approximately 40 ft. Unit thins to north where it ranges from 5 to 20 ft thick. Weathered zone ranges from 5 to 20 ft thick. As mapped, locally includes many small areas of fluvial and colluvial silt, sand, and gravel, especially at or near old wave-cut cliffs
- Qcu** Coastal terrace deposits, undifferentiated (Pleistocene) Semiconsolidated, moderately well sorted marine sand with thin, discontinuous gravel-rich layers. May be overlain by poorly sorted fluvial and colluvial silt, sand, and gravel. Thickness variable; generally less than 20 ft thick. May be relatively well indurated in upper part of weathered zone

## Figure 2 (continued): Aptos Creek Watershed Assessment and Enhancement Plan

### Geologic Unit Descriptions

- qd Quartz diorite (Cretaceous)- Grades to granodiorite south and east of Ben Lomond Mountain
  
- Qof Older flood-plain deposits (Holocene)- Unconsolidated, fine-grained sand, silt, and clay. More than 200 ft thick beneath parts of the Pajaro and San Lorenzo River flood plain. Lower parts of these thick fluvial aggradational deposits include large amounts of gravel, and serve a major ground-water aquifer beneath Pajaro Valley
  
- Qt Terrace deposits, undifferentiated (Pleistocene)- Weakly consolidated to semiconsolidated heterogeneous deposits of moderately to poorly sorted silt, silty clay, sand, and gravel. Mostly deposited in a fluvial environment. Thickness highly variable; locally as much as 60 ft thick. Some of the deposits are relatively well indurated in upper 10 ft of weathered zone
  
- Qtl Colluvium (Holocene)- Unconsolidated, heterogeneous deposits of moderately to poorly sorted silt, sand, and gravel. Deposited by slope wash and mass movement. Minor fluvial reworking. Locally includes numerous landslide deposits and small alluvial fans. Contacts generally gradational. Locally grades into fluvial deposits. Generally more than 5 ft thick
  
- Tbm Middle siltstone member- Thin- to medium-bedded, nodular , olive-gray pyritic siltstone. Thickness about 700 ft (Clark, 1981, p. 8)
  
- Tbu Upper sandstone member- Thin-bedded to very thick-bedded medium-gray , fine-to medium-grained arkosic sandstone containing thin interbeds of medium-gray siltstone. Thickness about 3,200 ft (Clark, 1981, p. 8)
  
- Tla Lambert Shale (lower Miocene) -Thin- to medium-bedded and faintly laminated olive-gray to dusky-yellowish-brown organic mudstone containing phosphatic laminae and lenses in lower part. Thickness about 1,500 ft along Mountain Charlie Gulch (Clark, 1981, p. 16)
  
- Tp Purisima Formation (Pliocene and upper Miocene)- Very thick bedded yellowish-gray tuffaceous and diatomaceous siltstone containing thick interbeds of bluish-gray semifriable, fine-grained andesitic sandstone. As shown, includes Santa Cruz Mudstone east of Scotts Valley and north of Santa Cruz. Thickness approximately 3,000 ft in the Corralitos Canyon area
  
- Tsl San Lorenzo Formation, undivided (Oligocene and Eocene)
  
- Tsm Santa Margarita Sandstone (upper Miocene)- Very thick bedded to massive thickly crossbedded yellowish-gray to white friable granular medium-to fine-grained arkosic sandstone; locally calcareous and locally bituminous. Thickness 430 ft along Scotts Valley syncline (Clark, 1981, p. 25)
  
- Tvq Vaqueros Sandstone (lower Miocene and Oligocene)- Thick-bedded to massive yellowish-gray arkosic sandstone containing interbeds of olive-gray shale and mudstone. Thickness 4,500 ft along Bear Creek (Burchfiel, 1958)
  
- Tz Zayante Sandstone (Oligocene)- Thick- to very thick-bedded, yellowish-orange arkosic sandstone containing thin interbeds of greenish and reddish siltstone and lenses and thick interbeds of pebble and cobble conglomerate. Thickness 1,800 ft along Lompico Creek (Clark, 1981, p. 14)

Geologic Unit	Abbreviation	Entire Watershed		Aptos Creek Sub Watershed		Mangels Gulch Sub Watershed		Trout Gulch Sub Watershed		Valencia Creek Sub Watershed	
		Area (acres)	Percent	Area (acres)	Percent	Area (acres)	Percent	Area (acres)	Percent	Area (acres)	Percent
Eolian Lithofacies	Qae	891	5.7	0	0.0	0	0.0	0	0.0	891	14.8
Fluvial Lithofacies	Qaf	219	1.4	0	0.0	0	0.0	0	0.0	219	3.6
Alluvial Deposits	Qal	387	2.5	103	1.3	46	8.4	127	8.5	109	1.8
Aromas Sand	Qar	580	3.7	0	0.0	0	0.0	106	7.1	474	7.9
Basin Deposits	Qb	58	0.4	0	0.0	0	0.0	0	0.0	58	1.0
Beach Sand	Qbs	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Lowest Emergent Coastal Terrace Deposit	Qcl	152	1.0	17	0.2	0	0.0	0	0.0	2	0.0
Coastal Terrace Deposits	Qcu	117	0.7	42	0.5	0	0.0	0	0.0	56	0.9
Quartz Diorite	qd	14	0.1	14	0.2	0	0.0	0	0.0	0	0.0
Older Flood Plain Deposits	Qof	282	1.8	13	0.2	0	0.0	9	0.6	190	3.2
Terrace Deposits	Qt	151	1.0	4	0.1	0	0.1	24	1.6	91	1.5
Colluvium	Qtl	858	5.5	0	0.0	0	0.0	0	0.0	858	14.3
Middle Sandstone Member	Tbm	315	2.0	315	4.1	0	0.0	0	0.0	0	0.0
Butano Sandstone	Tbu	179	1.1	179	2.3	0	0.0	0	0.0	0	0.0
Lambert Shale	Tla	2	0.0	2	0.0	0	0.0	0	0.0	0	0.0
Purisima Formation	Tp	9,816	62.5	5,344	69.2	499	91.6	1,224	82.2	3,071	51.0
San Lorenzo Formation	Tsl	997	6.3	997	12.9	0	0.0	0	0.0	0	0.0
Santa Margarita Sandstone	Tsm	13	0.1	13	0.2	0	0.0	0	0.0	0	0.0
Vaqueros Sandstone	Tvq	662	4.2	662	8.6	0	0.0	0	0.0	0	0.0
Zayante Sandstone	Tz	21	0.1	21	0.3	0	0.0	0	0.0	0	0.0

Table 1: Land surface area within each geologic unit by subwatershed. The geologic units with the highest percentage of land surface within each subwatershed are highlighted in gray. The Purisima Formation covers approximately 2/3rds of the entire Aptos Watershed.

### **1.2.2 – Erosion Sources**

A variety of landslides ranging from shallow debris flows to rotational slumps over a hundred feet deep are found in the Santa Cruz Mountains and the Aptos Creek Watershed. Landsliding (or mass wasting) is the dominant geomorphic process in the Santa Cruz Mountain landscape. Landsliding results from weak geologic formations, steep topography caused by tectonic uplift, and occurrence of intense periods of rainfall and seismic forces. Landslides often terminate at and impinge upon stream channels, sometimes feeding a seemingly endless supply of sandy material directly into the channels. In the worst cases, chronic sediment loading from landslides can eliminate pools, riffles and coarse substrate for hundreds of feet below the point of delivery. An important mechanism to store delivered sediment and attenuate sediment delivery downstream relates to the presence of large woody material and debris jams (Keller and Talley, 1979; Keller et al., 1981).





This is an example of woody material resulting in storage of coarse and fine material within the channel. Storage is likely to occur for approximately 100-200 feet upstream of the log.


Steep slopes are an important factor in erosion in general and for landslides in particular. Figure 3 shows slope class gradients for the Aptos Creek Watershed. The steepest slopes in the Aptos Creek Watershed are located in the Forest of Nisene Marks, along the headwaters near the summit and along the inner gorge slopes. The lowest gradients are found in the alluvial valleys along streams in the lower watershed areas.

Mapped landslides make up a substantial proportion of the overall sediment budget. The large slides are deep failures that often extend from ridge top to the canyon floor and stream. The speed of the active mass can range from inches per year to tens of feet per day. As a large slide moves along a distinct failure plane, the landmass on the upper part of the slide is lowered and depleted, while the lower toe area expands and bulges into the stream canyon or valley. The bulging of the toe has several significant effects on sediment delivery and

## Legend

 Rivers and Streams

 Sub-Watershed  
Boundaries

 Aptos Creek Watershed  
Boundary

### Slope Classes (in percent)

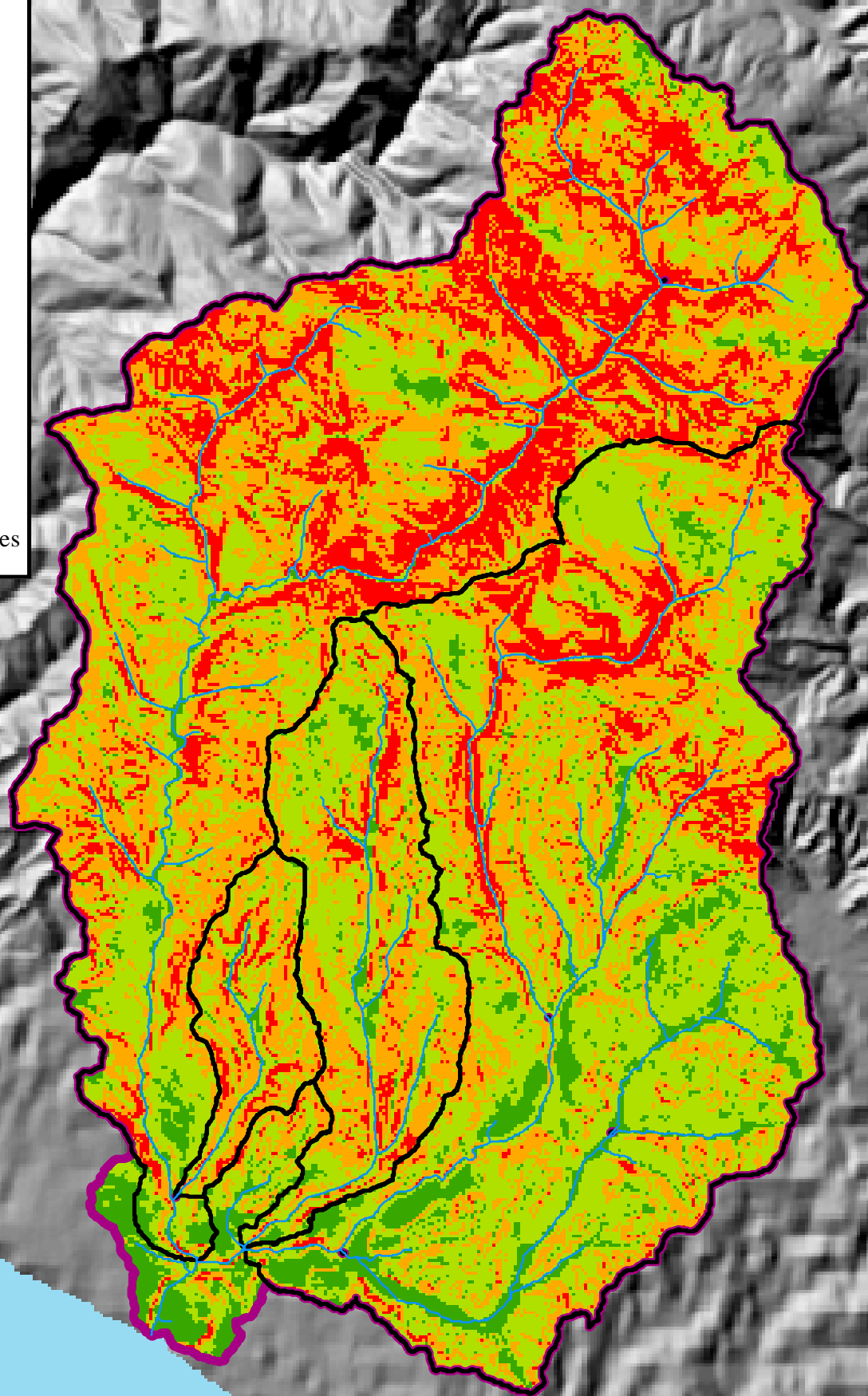
 < 10

 10 - 30

 30 - 50

 > 50

Scale is 1:54,000 or 1 inch = .85 miles



sensitivity to land disturbance. First, the rock is fractured, weakened and subject to saturation and greater weathering while it is being transported closer to the stream; this makes the mass simultaneously steeper and weaker, enhancing gully erosion and shallow mass failures on the toe face. As the stream incises or if a road is cut along the canyon wall, the landslide toe is eroded and the mass buttressing the slide above is removed, causing the slide to move further down slope. This lower zone of canyon slopes where incision dominates is called the "inner gorge". The inner gorge is generally steeper than the hillslope above and in addition to landslide toes, which often contain deeply weathered bedrock and colluvium.

Weathered bedrock, soils and colluvium are subject to saturation by rainfall. Saturated conditions can produce a nearly instantaneous and deadly failure of a rapidly moving landslide called a *debris flow*. Debris flow failures are common along the inner gorge slopes of the Santa Cruz Mountains. Debris flows occur during intense periods of rainfall after hundreds of years of persistent slope wash and colluvium accumulation in swales. The swales are often bedrock, which has a lower permeability than the overlying colluvium. When the rate of rainfall exceeds the rate that the colluvium and soil can drain water off, the saturated zone or water table above the less permeable bedrock deepens. When the saturated mass overcomes the resistance holding it on the hillslope, the mass liquefies instantly and moves down the hillslope carrying trees, soil, propane tanks and sometimes entire houses. In some cases, water separates from the debris flow mass as it reaches lower gradients and a debris torrent is unleashed - a wall of mud and debris that moves very fast and is extremely destructive. Debris flows and torrents commonly form the small alluvial fans distributed along the edges of higher order stream valleys at the end of ephemeral tributary basins. In the January 2-4, 1982 storms, debris flows and nearly continuous shallow failures in the inner gorge slopes occurred throughout the Santa Cruz Mountains.

Road building is a common and often dominant theme in land use disturbance. From timber harvests to driveways and public thoroughfares, roads are required for access to nearly every land use. Roads are also by far the most destructive element in the landscape as far as excessive fine sediment generation per unit area. Roads constructed along canyon floors and steep inner gorge slopes cause channel realignment resulting in direct delivery of sediment to streams.

Erosion from road surfaces, ditches, shoulders and other human-induced land clearing contribute mostly fine-grained sediment. Paved and unpaved roads modify local hillslope drainage patterns, concentrate flow and increase runoff rates. Runoff on roads concentrates over soils exposed on the roadbed and shoulder, drainage ditches, road cuts, sidecasts and fills. In terms of managing sediment loads to reduce aquatic habitat impairment, fine sediment source reduction from roads will be the most effective treatment. Roads are the primary cause of human-induced or "accelerated" erosion throughout the Santa Cruz Mountains from both timber harvest activities and rural residential roads.

Bank erosion and reworking of old floodplain deposits also contributes significantly to the amount of fine sediment in the channel. These sources contribute fine sediment directly to the channel and have a significant impact on aquatic habitat conditions. Reworking of old floodplain deposits that might have been delivered to the stream channel due to historic and intensive logging operations may be especially important in the Valencia and Trout Creek watersheds due to urbanization impacts that affect the hydrologic regime. To what extent reworked floodplain deposits has an impact on aquatic habitat conditions is largely unknown. Several researchers have attempted to describe a predictable evolutionary sequence of

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channel response to urbanization (Simon, 1989; Arnold et al., 1982; Gregory et al., 1992; Park, 1997).

Once model, developed by Douglas (1985) describes a conceptual relationship between land use changes, relative sediment yield, and channel stability. At the onset of urban development, this model suggests the sediment yield would be very heavy due to increased runoff from impervious surfaces, resulting in increased gully, undercutting, and bank erosion. The impact on channel stability would be rapid aggradation and some bank erosion. Assuming no net increase in urbanization, the Douglas model predicts that a watershed would proceed through a period of stabilization that would last on the order of 25 years. During this period sediment yields would be moderate as channels adjusted to the new hydrologic condition and readily available sediment supplies were exhausted. Reduced sediment yields during this transitional period would result in channel degradation and severe bank erosion. Eventually, the channel is expected to reach a stable urban condition with low to moderate sediment yields and a relatively stable channel. This whole channel evolutionary process is expected to take 50-75 years due to lags in land use change and channel response. The timing would be highly dependent upon the size of the watershed, the rate of urbanization, and the time it takes for land use conditions to stabilize.

## 2.0 – METHODS

### 2.1 – SEDIMENT BUDGET

Development of a sediment budget is an approach that considers the erosional processes occurring in a particular study area and attempts to quantify the amount of material being delivered and transported past a specific point. If the amount of sediment being delivered exceeds the amount of sediment being transported, aggradation is the dominant process. If the amount of sediment being transported exceeds the amount being delivered, the stream channel is likely to be incising. If both delivery and transport of sediment are equal, the stream channel is said to be in equilibrium.

This simplified notion of a sediment budget is complicated by the fact that both sediment delivery and transport within a stream channel is a stochastic process (Benda and Dunne, 1997a; Benda and Dunne, 1997b). This means that sediment delivery to the channel occurs episodically through mass wasting events such as landslides or debris flows. Sediment transport is also a function of the magnitude, duration, and energy associated with streamflow, which has a significant range over time periods as short as a few hours. Sediment transport volumes during wet years can be orders of magnitude greater than those recorded in drought years. The same is true for sediment delivery. During wet years, a saturated hillslope in the steep inner gorge is much more likely to fail and deliver sediment to a stream channel than the same hillslope during a dry year. Over time, it is likely that episodic delivery and transport events even out, producing what is known as a system in dynamic equilibrium. The question often remains, over what time scale is the concept of dynamic equilibrium occurring within any given reach of stream.

The stochastic nature of sediment delivery and transport makes it very difficult to accurately estimate a sediment budget given limited data. Monitoring movement of suspended and bed load material passing a set location, such as a bridge, would require one to two decades of data to capture the range of flow and sediment events that characterize the stochastic nature of the process. It would not be uncommon for a single year, within a 20-year dataset, to represent over 50% of the total sediment load measured during that period. If that single year were removed, the average flux of sediment, per year, would be greatly underestimated.

There are also difficulties in estimating the supply side of the sediment budget equation that go beyond the stochastic nature of the process. In many cases it is very difficult to apply a rate to any particular erosion source. Sources of erosion can easily be identified in the field, and the volume of sediment being eroded and delivered to an adjacent stream channel can be estimated. The difficulty lies in estimating the rate at which the sediment is being delivered. Without information about how long ago a particular source began to erode, volume information becomes meaningless.

In some cases this problem has been overcome through the use of aerial photo series. Several photo dates can be examined to constrain the date at which a particular erosion feature, such as a landslide, began delivering sediment. By estimating sediment volumes from many landslides throughout a particular watershed from a series of aerial photos, a landslide rate for the landscape of interest can be estimated (Reid and Dunne, 1996). Unfortunately, aerial photo interpretation of erosion features becomes problematic in a landscape with dense tree cover. Features such as landslides, debris flows, or gullies are in most cases impossible to see, unless they are recent or very large. Mapping these features in a densely forested area with the intent of estimating a sediment budget can be very misleading.

The quality of the results generated from a sediment budget will ultimately be related to the quality of the input data and the amount of time and information that is available to accurately construct one (Reid and Dunne, 1996). To accurately quantify the rate at which sediment is being supplied to the channel would require years of intensive data collection and monitoring equipment, as well as access to all, or a statistically random subsample of potential sources. Since an intensive approach is not feasible, the best approach lies in identifying the most significant sources of sediment, obtaining as much information as possible about the physical setting of the landscape that might infer a certain rate of erosion, and applying published erosion rates from other watersheds that exhibit similar patterns of erosion.

Regardless of the difficulties in estimating sediment budgets, particularly in forested areas, the results can be a valuable dataset when attempting to understand the dominant erosional processes and the sources of sediment that may be impairing aquatic habitat. The exercise of estimating a sediment budget requires careful consideration of each potential source, the magnitude of delivery by that source, a description of the grain-sizes being delivered, and a comprehensive understanding of the transport hydraulics within a stream channel. Even though the final sediment budget numbers may contain a significant amount of error, there is much to be understood from them. The magnitude to which each source contributes to the overall sediment budget and the location of those sources within the watershed, as a whole, are valuable pieces of information that can guide current and future management.

The remainder of this section will describe the approach used to estimate a sediment budget for the Aptos Creek Watershed. Much of the approach is based on erosion estimates developed by the California Department of Forestry (CDF) for the Soquel Demonstration Forest (Cafferata and Poole, 1993) and utilized effectively in the Zayante Area Sediment Source Study (Swanson and Dvorsky, 2001). Though there is some concern about the accuracy of the CDF study, it is still considered to be the most comprehensive attempt at measuring erosion rates in forested watershed of the southern Santa Cruz Mountains.

### **2.1.1 – Subwatershed Delineation**

The first step in developing a sediment budget is to determine the location at which we are interested in quantifying the amount of sediment being transported through the system. Since we are concerned about the conditions of the entire watershed, the most logical location would be at the mouth of Aptos Creek as it enters the Pacific Ocean. Upstream of this location lies a variety of subwatersheds that exhibit different morphologic, geologic, and land use conditions that must be considered to accurately estimate rates of erosion and sediment input to the stream channel.

To capture the variability in landscape and land use conditions in the watershed, while at the same time taking advantage of the dendritic nature of stream channels, we divided the watershed into subwatershed areas, as defined by the confluence of tributary inputs and/or significant changes in the dominant rock type (Figure 4). Subwatersheds were delineated automatically using a USGS 30-meter digital elevation model of the landscape based on points manually selected that represented the lowest “pour point” within each subwatershed. Standard GIS algorithms were used to derive the subwatershed boundaries from the input digital data source.

## Legend

 Paved Roads

 Streams

 Aptos Creek Watershed


## Sub-Watersheds

 Valencia Creek Sub-Watershed

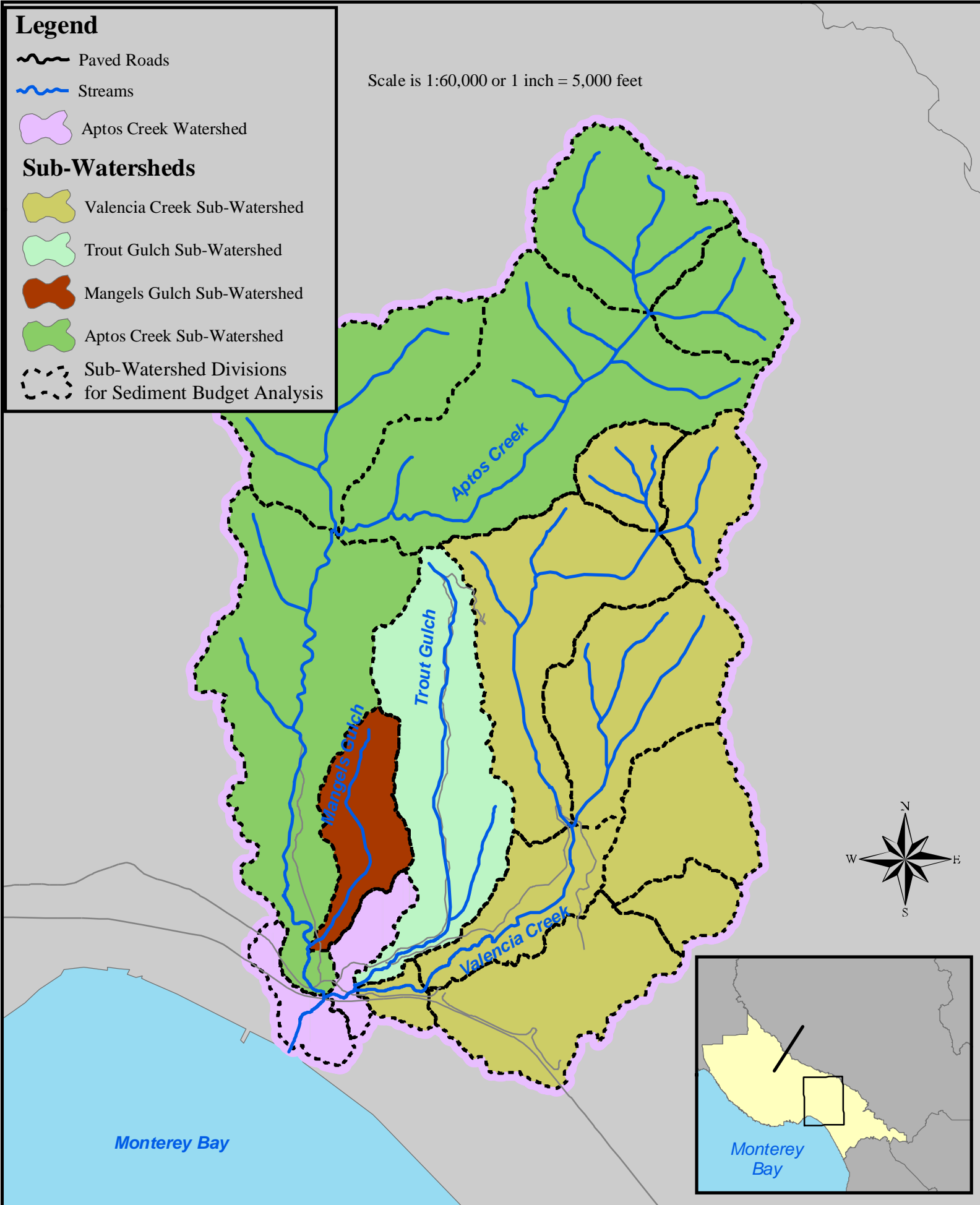
 Trout Gulch Sub-Watershed

 Mangels Gulch Sub-Watershed

 Aptos Creek Sub-Watershed

 Sub-Watershed Divisions  
for Sediment Budget Analysis

Scale is 1:60,000 or 1 inch = 5,000 feet



Aptos Creek Watershed  
Sub-Watershed Delineation

Figure 4

The derived watersheds were the primary analysis units used to calculate erosion from the landscape and estimate sediment delivery to the channel, except for the bank erosion component of the sediment budget, which used stream reach delineations (discussed later). A total of 18 subwatersheds were delineated for the Aptos Creek Watershed. The subwatersheds range in size from 100 acres (the area below the confluence of Aptos and Valencia) to 2,300 acres (Upper Aptos Creek), with an average size of approximately 870 acres (1.35 mi<sup>2</sup>).

To simplify reporting of the final sediment budget, the subwatersheds were combined into four subwatershed areas representing Aptos, Mangels, Trout, and Valencia Creeks. Information generated for each analysis-level subwatershed was combined using a drainage area weighted average of the per unit sediment yield.

### **2.1.2 – Sediment Budget Calculations**

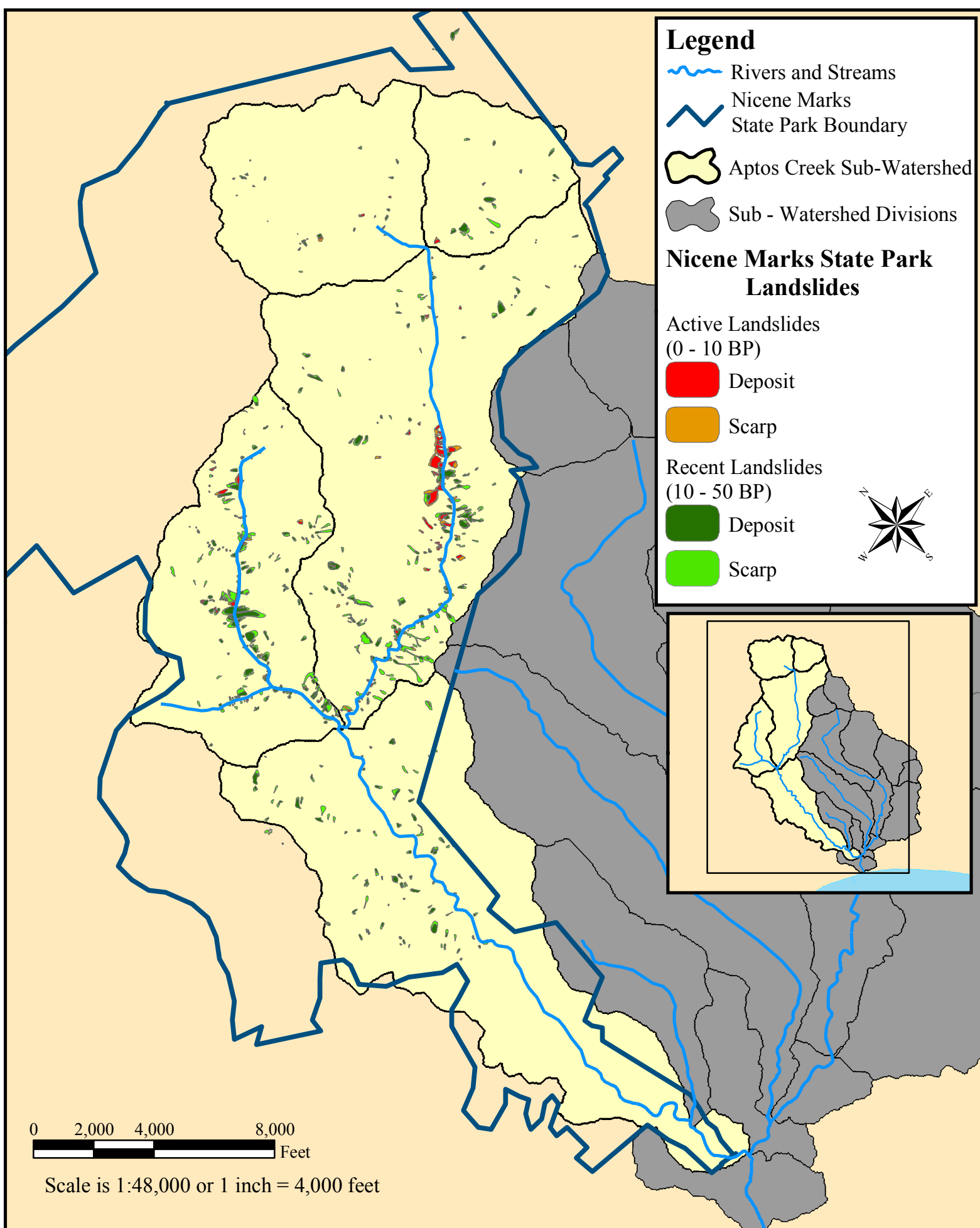
#### ***Mass Wasting***

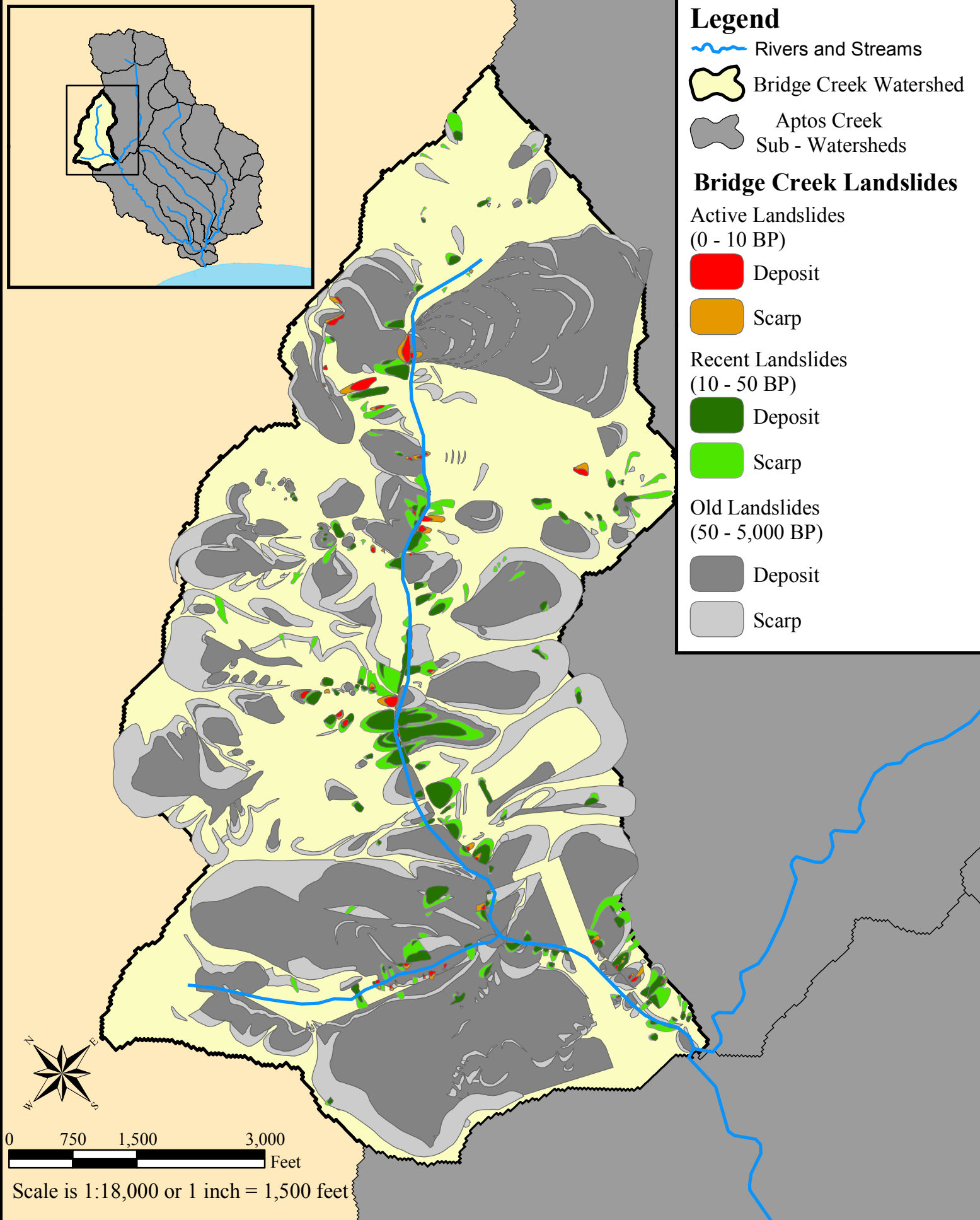
In the Zayante Area Sediment Source Assessment (Swanson and Dvorsky, 2001), the best data available to estimate erosion and delivery rates from mass wasting was a USGS GIS product depicting landslides for Santa Cruz County (Cooper-Clark and Associates, 1974). This product, though useful for identifying the density of landslides on the landscape, provides no information regarding the age of the landslide. Without age information, an erosion rate is difficult to calculate and must be grossly estimated.

Fortunately, for the Aptos Creek Watershed, a wealth of information is available for the Forest of Nisene Marks State Park portion of the watershed. Following the Loma Prieta earthquake that occurred in October of 1989, Weber and Nolan (1992) were funded to map landslides, using field identifications in Nisene Marks, with special attention paid to recent landsliding associated with the Loma Prieta earthquake. In addition to the location and extent of each landslide, general information was collected regarding the type of landslide (e.g. – rotational, translational, debris flow) and an estimate of the age within an age category consisting of those occurring within the last 10 years, the last 50 years, and older. Each landslide was mapped on a 1:24,000 USGS quadrangle.

SH&G acquired the original landslide maps and produced a digital version by digitizing each feature (Figure 5). Each feature was assigned attributes defining the estimated age of the slide and whether the feature was a slide mass or a scarp. Information regarding the mechanism was excluded from the GIS database. Since the volume of data was immense, only slides estimated to have occurred within the last 50 years were digitized for the entire study area within the Aptos Creek Watershed. In the Bridge Creek subwatershed, all features depicted on the maps were digitized so as to provide a complete dataset for one subwatershed (Figure 6). Only mass wasting features determined to be recent were included in the sediment budget calculations.

The final piece of information required to estimate the volume of sediment that was available from each mass wasting feature is an average depth for each slide mass. Unfortunately, the landslide map does not provide the necessary information to determine this. The volume of sediment from each feature was estimated by assuming an average depth of ten feet. A depth of ten feet was assumed since a large proportion of the recent slides were determined to be of the shallow, translation type, rather than deep rotational slides (Weber and Nolan, 1992). The surface area of the slide mass was used with this average depth to calculate a volume for each





slide. The volumes were then used to estimate sediment yield rates according to the age of each mass wasting feature. An assumed age of 50 years was used for the recent slides while the active slides were assumed to be 10 years old. They represent the estimated maximum age of the slide according to the mapping data and are therefore considered to be a conservative estimate of the erosion rate.

In order to convert a sediment volume to a mass, we assumed a soil density of 123.5 lbs/ft<sup>3</sup> (Holtz and Kovacs, 1981). This is based on the predominance of fine-grained sand in the geologic and soil material within the watershed. Soils associated with mass wasting events would likely be moderately consolidated, as opposed to reworked material that might be found on the banks of the channel.

Since the landslide data was only available for the portion of the Aptos Creek Watershed found within the Forest of Nisene Marks, it was necessary to approximate the sediment volumes due to mass wasting for areas outside of the Park boundaries. This requires a rough, qualitative assessment of the geologic and slope characteristics of the watershed. Weber and Nolan (1992) suggested that high landslide rates in Nisene Marks were associated with instability along the fold axis of the Glenwood Syncline. The Glenwood Syncline crosses subwatersheds 3 and 4 (*see Figure 4*) in the Aptos Creek subwatershed and 6 and 7 in the Valencia Creek subwatershed. To calculate landslide rates for subwatersheds 6 and 7 in Valencia, we applied a weighted average, normalized by subwatershed area, from subwatershed 3 and 4 in Aptos. The remaining subwatersheds in Mangels, Trout, and Valencia were assigned weighted average values from mapped subwatersheds outside of the influence of the Glenwood Syncline (subwatersheds 1, 2, and 9). The developed/urban areas in the lower Valencia and Aptos Creek subwatersheds were assumed to not experience significant mass wasting due to low slopes and urbanization (subwatershed 17, 18, 21, and 23).


### ***Bank Erosion***

Bank erosion was estimated along a good portion of all the primary channels within the Aptos Creek Watershed, including Aptos, Bridge, Mangels, Trout, and Valencia. Field measurements were completed alongside the fisheries and large woody material surveys and were compiled by stream reach (Figure 7). Reaches were delineated based on Rosgen's (1994) stream channel classification, which divides and classifies a stream based on local stream and valley morphology, gradient, and sediment characteristics. Each stream reach was walked and all significant bank erosion sites were either measured or the length of each erosion site was estimated using a hip chain measuring device to determine distance along surveyed stream reaches. The height of the bank erosion site was either measured directly using a stadia rod or was visually estimated. Information regarding the dominant grain size, the severity, and the level of stability were noted for each site.













This information was then used to estimate the total area (in ft<sup>2</sup>) of bank erosion along each surveyed reach. The total length of each reach was then used to calculate an erosion area per mile of stream (ft<sup>2</sup>/mi). This rate was then applied to all unsurveyed streams occurring within the same analysis subwatershed, with the assumption that the unsurveyed segments exhibit the same bank characteristics as the surveyed segment. We realize this assumption may not accurately depict the true erosion rate from streambanks due to differences between primary trunk streams and smaller tributaries, but we feel it is the best estimate available. It is unclear whether this assumption results in an over or under estimate of the eroding bank area.

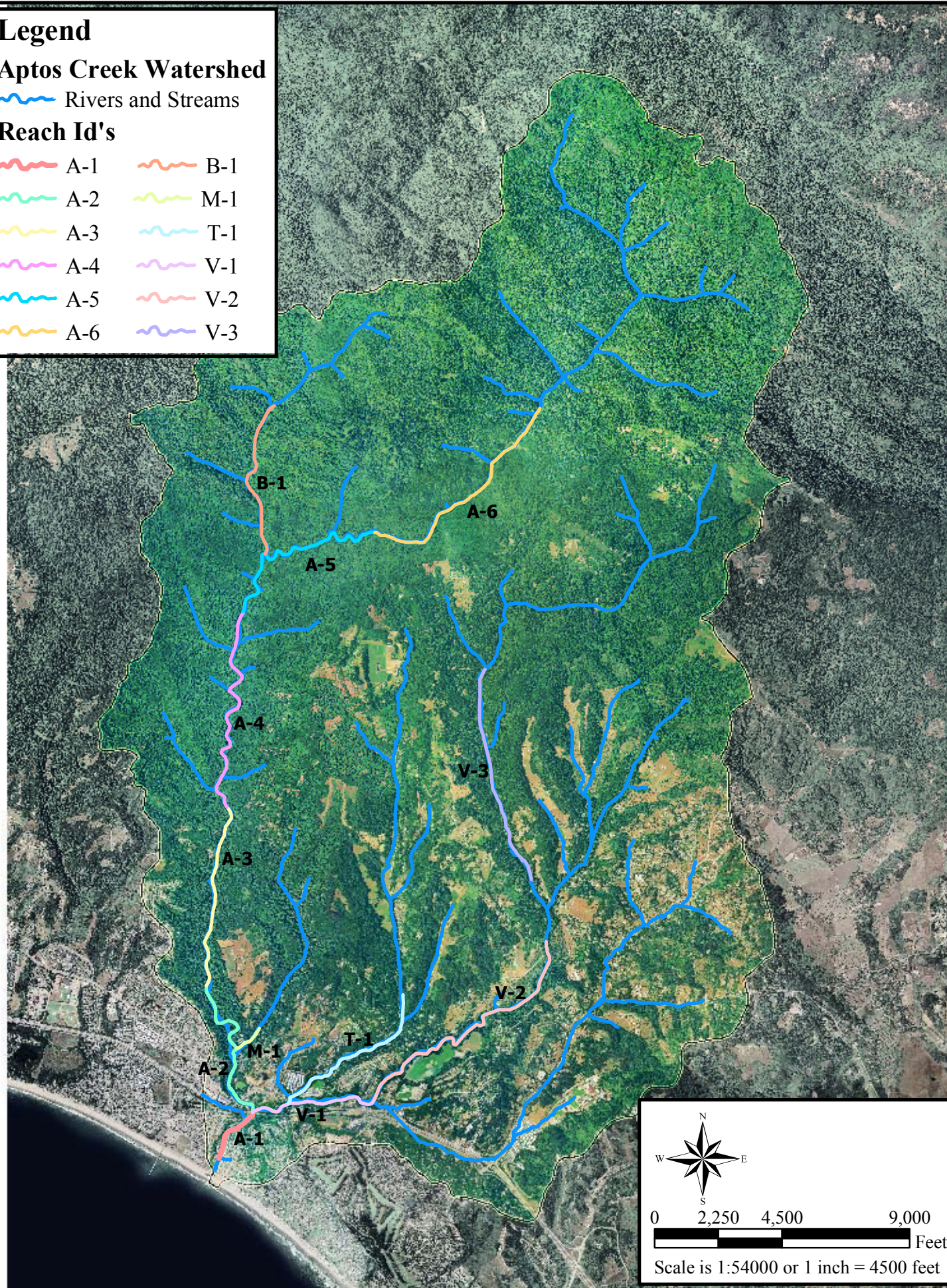
## Legend

### Aptos Creek Watershed

 Rivers and Streams

### Reach Id's

 A-1	 B-1
 A-2	 M-1
 A-3	 T-1
 A-4	 V-1
 A-5	 V-2
 A-6	 V-3



The method described above only provides a two-dimensional picture of bank erosion in the Aptos Creek Watershed and does not allow for a direct calculation of the erosion rate. To make the jump from an erosion area to an erosion rate, we made several assumptions about the average depth and age of the observed bank erosion sites. Many of the erosion sites observed consisted of shallow composite failures due to undercutting. Based on this observation, we assumed the average depth was 2 feet. We also assumed an average age of 10 years. Bank erosion sites older than that would probably not be evident due to regrowth of vegetation, except in the case of chronic sites associated with landsliding. Those assumptions produce a retreat rate of 0.2 feet per year.

The estimated retreat rate was then used in conjunction with the area of erosion per mile of stream to produce a bank erosion sediment yield per mile of stream within each subwatershed ( $\text{ft}^3/\text{mi}/\text{yr}$ ). To convert a volume to a mass, a value of 87.9 lbs/ $\text{ft}^3$  was used (Holtz and Kovacs, 1981). Bank deposits were assumed to be less dense than virgin landslide material and therefore a published rate associated with loosely consolidated silty sand was used.

### ***Roads***

In the absence of a comprehensive dataset of road-related erosion and the level of effort that would be required to generate such information, we utilized sediment yield estimates from a CDF study of the East Branch of Soquel Creek (Cafferata and Poole, 1993). The Cafferata and Poole study occurred in an adjacent watershed and is likely to be the best locally available information on sediment yield off of both paved, dirt, and forest roads. This information was utilized successfully in the Zayante Area Sediment Study (Swanson and Dvorsky, 2001) and the San Lorenzo River TMDL (Angelo, 2002). The Aptos Creek Watershed is likely to be more suited for using this data due to the similarities in geology, topography, and vegetation, compared to the Zayante Area, which is more urbanized and geologically distinct.

Some recent criticism has been directed towards the CDF study claiming that several study plots monitored by Cafferata and Poole overestimate actual erosion rates, skewing study results. It has been suggested that discrete features within the study plots account for a significant portion of the measured sediment yields and should be considered outliers and not be included in the final results. Though this point may be valid, if such features are removed from the dataset, the final result may not be completely representative of the erosion process, which is stochastic and episodic by nature. As mentioned earlier in this report, accurate measurement of long-term sediment yields must capture anomalies in order to be accurate. It is these anomalies that often, and accurately, account for a significant portion of the total yield. It would be beneficial to conduct further studies to better constrain erosion rates in the Santa Cruz Mountains. Until those studies are completed, Cafferata and Poole is the best estimates we have.

To apply the erosion rates developed for the East Branch of Soquel, a GIS road layer from the Santa Cruz County GIS database was used to determine the length of road coverage per analysis subwatershed (Figure 8). Additionally, a GIS road layer representing known dirt roads that exist within the Forest of Nisene Marks was digitized by the Coastal Watershed Council and utilized. Road data depicting residential and logging roads are not included in the County database. We recognize this as a gap in the road erosion analysis. To differentiate between roads that occur along the sensitive “inner gorge” of the stream valley and those further away from direct sediment input to the channel, a buffer was used to classify the road network. The buffer was varied by stream order with 1<sup>st</sup> order streams

## Legend

 Paved Roads


 Dirt Roads

 Streams

 Aptos Creek Watershed

## Sub-Watersheds

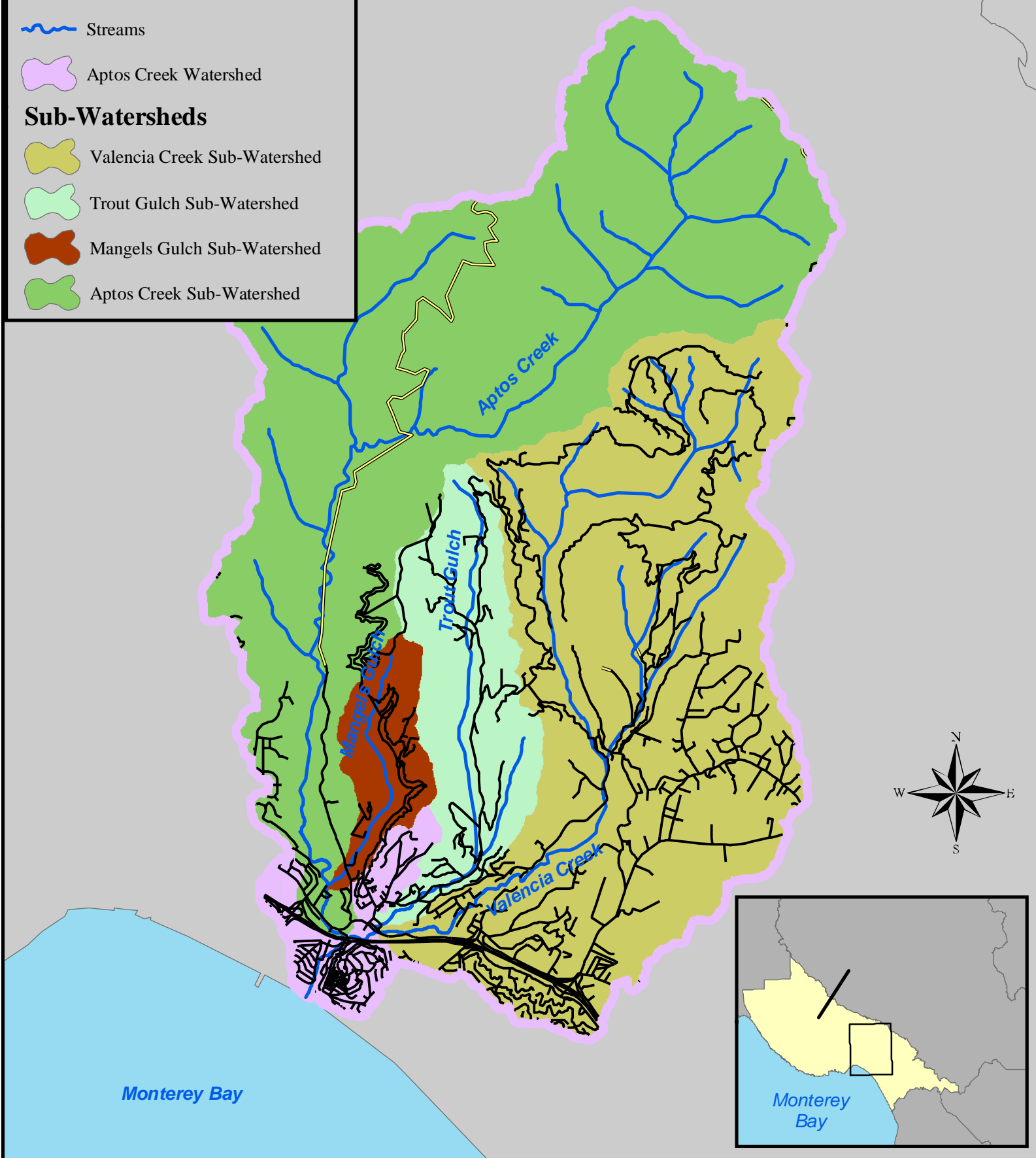
 Valencia Creek Sub-Watershed

 Trout Gulch Sub-Watershed

 Mangels Gulch Sub-Watershed

 Aptos Creek Sub-Watershed

Scale is 1:60,000 or 1 inch = 5,000 feet



Aptos Creek Watershed  
Location of Paved and Dirt Roads

Figure 8

having a buffer of 50 feet, 2<sup>nd</sup> and 3<sup>rd</sup> order stream were given a buffer of 100 feet, and 4<sup>th</sup> order or greater streams were given a buffer of 150 feet. All roads occurring within this buffer were considered to be “inner-gorge” roads. All other roads were considered to be hillslope roads (Table 2).

Following separation of the roads into different classes, the total road mileage for each road class within each analysis subwatershed was calculated from the GIS database. Erosion rates from the CDF study were used to calculate the volume of sediment yielded from each of the four classes of roads in each subwatershed. Soils eroded from road features were designated as silty sand. Assuming that soils associated with road erosion features are moderately consolidated, the soil density was assumed to be 123.5lbs/ft<sup>3</sup> (Holtz and Kovacs, 1981).

**Table 2:** Sediment source yield estimates for road features in Aptos Creek Watershed.

Sediment Source	Sediment Yield from Soquel (CDF, 1993)	Sediment Yield assuming soil density is 123.5 lbs/ft <sup>3</sup>
Paved Inner Gorge Roads	46.8 yd <sup>3</sup> mi <sup>-1</sup> yr <sup>-1</sup>	78 tons mi <sup>-1</sup> yr <sup>-1</sup>
Dirt Inner Gorge Roads	360 yd <sup>3</sup> mi <sup>-1</sup> yr <sup>-1</sup>	600 tons mi <sup>-1</sup> yr <sup>-1</sup>
Paved Hillslope Roads	46.8 yd <sup>3</sup> mi <sup>-1</sup> yr <sup>-1</sup>	78 tons mi <sup>-1</sup> yr <sup>-1</sup>
Dirt Hillslope Roads	360 yd <sup>3</sup> mi <sup>-1</sup> yr <sup>-1</sup>	600 tons mi <sup>-1</sup> yr <sup>-1</sup>

### ***Other Lands***

Erosion off of “other lands” is meant to be a catch-all category for sources associated with rilling, gullying, overland flow, or erosion from temporarily disturbed land or bare areas. Since this type of erosion is very difficult to measure without conducting a comprehensive study, sediment input from urban and rural lands was accounted for by utilizing sediment yield values from the study conducted on the East Fork of Soquel Creek by CDF (Cafferata and Poole, 1993). In the CDF study, erosion from urban and rural land also included mass wasting. Since we already accounted for much of the mass wasting in our previous calculations, the erosion rate from the Soquel study was reduced to only reflect a sediment rate that does not include mass wasting sources. In the Zayante Area Sediment Study, the remaining amount associated with non-mass wasting sources from rural and urban lands was assumed to be 50% of the value reported in the CDF study. Given concerns about the validity of the erosion estimates and skewing of the results due to a single large gully, we reduced the non-mass wasting sources to 25% of the reported value from the CDF study. To account for urbanization and impervious surface impacts in the Mangels, Trout, and Valencia Creek subwatersheds, we multiplied the resulting erosion rate by a factor of 1.24 and applied it to these subwatersheds. At this time we cannot confirm if this is an accurate representation of the conditions present in the Aptos Creek Watershed but feel it is important to adjust the values to observed local conditions.

Soils eroded from urban and rural lands were designated as silty sand. Assuming that soil eroded from urban and rural lands are moderately consolidated, the dominant soil density of these features is estimated to be 123.5 lbs/ft<sup>3</sup> (Holtz and Kovacs, 1981). Sub-watershed areas were estimated using the subwatershed GIS layer to calculate the sediment yield for each sub-watershed. The final assumed erosion rate for Aptos was 1,548 tons/mi<sup>2</sup>. For Mangels, Trout, and Valencia, the final rate was 1,935 tons/mi<sup>2</sup>.

### **2.1.3 – Delivery Efficiency**

Delivery efficiency is an important element of any sediment budget because it defines the proportion of sediment that actually makes it to the channel, as opposed to being deposited on the hillslope or the inside ditch of a road. The delivery efficiency of any specific grain is ultimately related to rainfall rates, length of the drainage pathways, and proximity of the sediment source to a waterway. The precise fate of any single grain of sediment is difficult to know, but general assumptions can be made about the delivery efficiency of a particular source class.

To maintain consistency with the Zayante Area Sediment Study and the San Lorenzo TMDL, we used identical delivery efficiencies for sediment sources in the Aptos Creek Watershed, if the information was available (Table 3). For landslides, it was assumed that the slide mass likely terminated at a stream channel, but given the fact that much of the material remains on the hillslope, a low delivery efficiency was assigned to this sediment source (20%). The toe of the slide mass will continually erode but this process is likely to occur over a period of several decades with much of the slide mass reestablishing vegetation and stabilizing. Conversely, bank failures likely result in 100% delivery of sediment to the active channel with very little material remaining perched for later delivery.

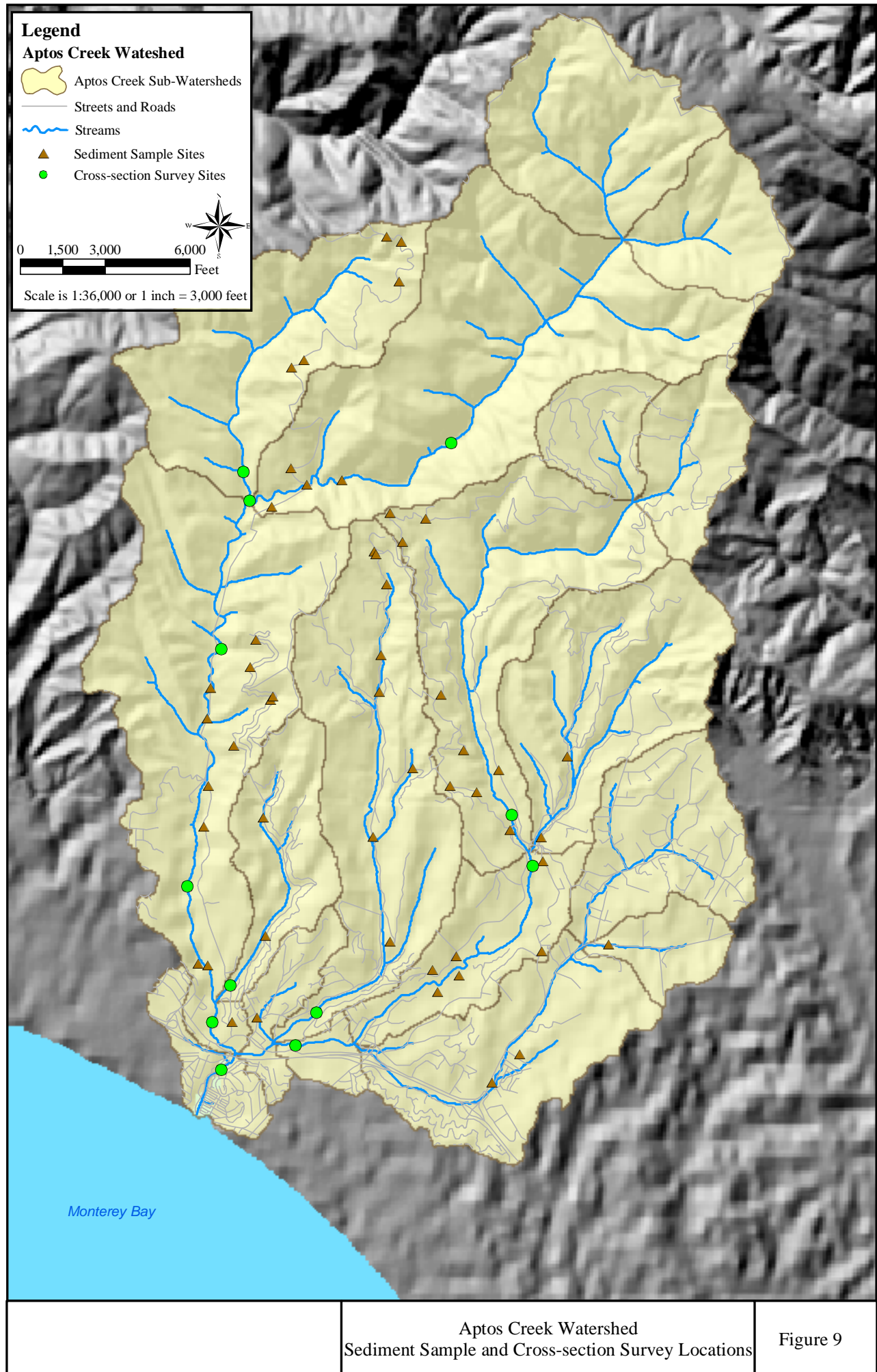
**Table 3:** Sediment delivery efficiencies for each sediment source.

<b>Sediment Source</b>	<b>Sediment Delivery Efficiency</b>
Mass Wasting	20%
Bank Erosion	100%
Inner Gorge Roads	100%
Hillslope Roads	42%
Urban and Rural Lands	42%

### **2.1.4 – Grain-size Analysis**

Though it is not essential to have grain-size information in order to estimate a sediment budget, grain-size from sediment sources in a watershed can provide important data regarding the type of sediment that is being delivered and how that sediment might be transported through the stream system. Given that the ultimate goal of this assessment is to determine the condition of aquatic habitat and the impact that fine-sediment input may be having on salmonid production, we felt it important to determine the proportion of fine sediment being eroded from the hillslopes and into the stream channel compared to the total mass of sediment.

To accomplish this, SH&G staff visited 52 sites throughout the Aptos Creek Watershed and collected sediment samples that were representative of the material being eroded from the site (Figure 9). The erosion sites were fairly well distributed across the landscape and included an even sample of all the types of erosion sources in the watershed including landslides, roadside ditches, exposed areas associated with construction sites, bank erosion areas, road cuts, and road shoulders. Sample locations were mapped on a USGS 1:24,000 quadrangle map. Collected samples were dried in an oven and a 100 mg subsample was sieved using a portable hand-held sieve. Given the lack of coarse material in all of the samples, we felt a 100 mg sample was adequate to reflect the grain-size distribution. Sieve sizes of 1.7, 1.18, 0.85, and 0.6 millimeters were used in the analysis. The entire sample was retained in case more analysis of the sample is required in the future.



### 2.1.5 – Sediment Flux in Aptos Creek

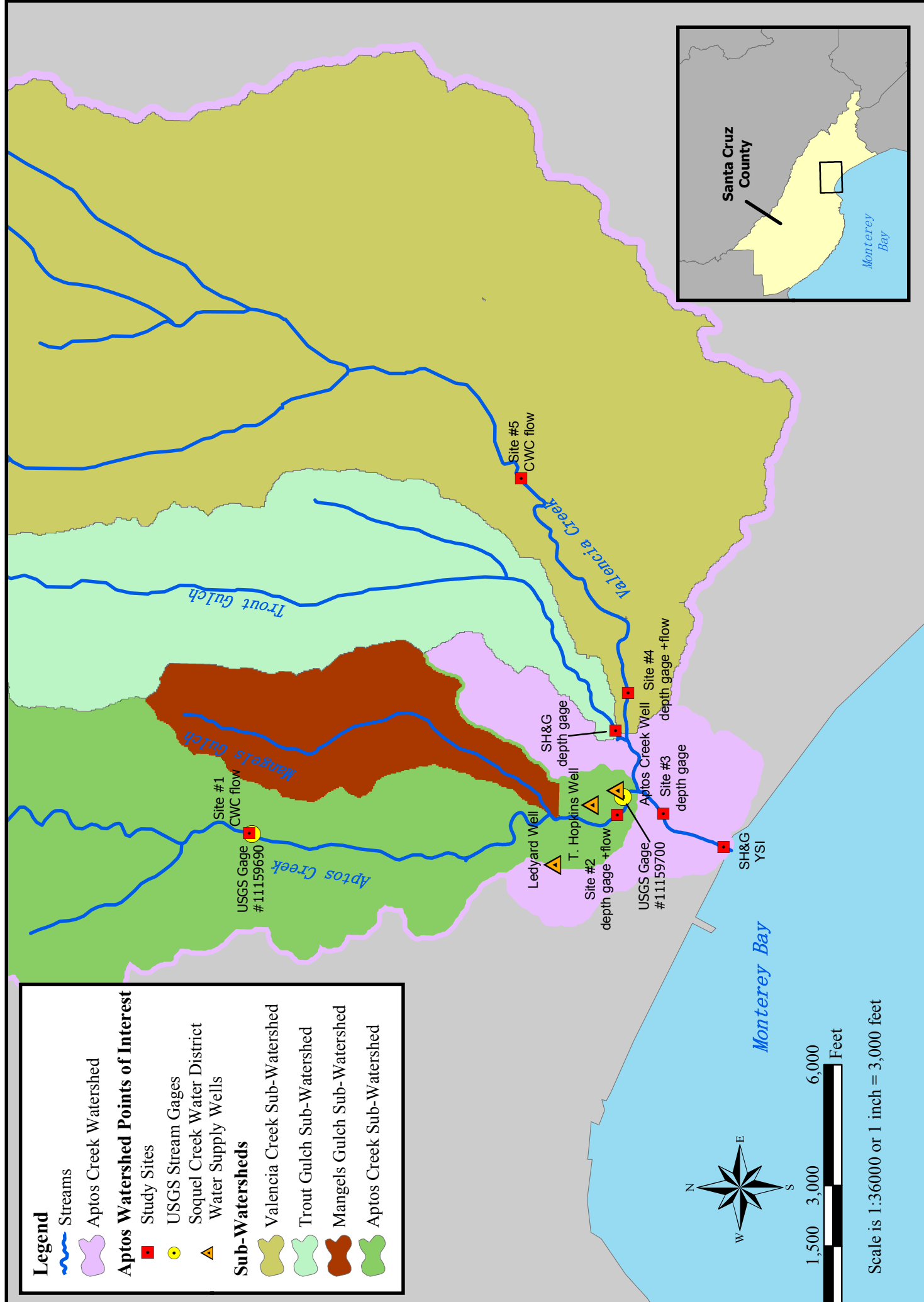
A complete sediment budget requires information about the amount of sediment being delivered to the channel (I) as well as the amount of sediment being transported past the point of interest (O). Any imbalance between the input (I) and the output (O) is assumed to be the change in storage in the system (S). A positive storage value suggests that sediment is being stored in the channel through aggradation of the bed or is being stored in floodplain or bar deposits. A negative storage value suggests channel downcutting.

In order to estimate the Output term of the sediment budget equation, streamflow, suspended sediment, and bedload data must be available. The most often used data of this type is available from the U.S. Geological Survey (USGS) who maintain an extensive network of streamflow gages and water quality monitoring sites throughout the country. Unfortunately, many of the gages historically supported by the USGS have been abandoned due to budget cuts and a lack of interest in long-term hydrologic monitoring (Rodda, 1998). Water quality data, including periodic measurements of suspended and bedload, were not supported at all streamflow monitoring sites and, therefore, constitute a spotty dataset to begin with.

The USGS historically supported two streamflow gages on Aptos Creek, upstream of the Valencia Creek confluence (*see the Hydrology and Water Quality Technical Memorandum*). One gaging site was supported from 1959 to 1972 (Gage ID #11159700) and monitored a drainage area of 12.3 mi<sup>2</sup>. The other site was supported from 1972 to 1985 (Gage ID #11159690) and monitored a drainage area of 10.2 mi<sup>2</sup>. At both of these sites no water quality information was collected, except during a few low magnitude events. Each monitoring site was primarily equipped with a streamflow gage that provided a continuous record of average daily flow for the monitoring period.

As part of the hydrologic and water quality technical studies for the Aptos Creek Watershed Assessment, four temporary streamflow gages were established. The four sites consisted of water level recorders installed near the Spreckels Bridge, on Aptos Creek adjacent to the County Park, and on Valencia and Trout adjacent to the Valencia School for the 2002 Water Year (Figure 10). Along with water level and streamflow data, suspended sediment samples were collected periodically during the rainy season to determine suspended sediment concentrations (SSC) within each of the tributaries during peak flow events. A DH-49 depth integrating hand-held suspended sediment sampler was used at each site. Due to time constraints, only a single vertical, in the center of the channel, was collected at each site, and was assumed to be representative of the cross-section. Each sample was then taken back to a lab where it was filtered and weighed to determine the SSC.

From the SSC data collected at the County Park site on Aptos Creek (Site #2), we developed a rating curve relating SSC to discharge values obtained from the water level data collected at the site. Since W.Y. 2002 lacked high magnitude peak flow events, the rating curve only represents the lower, more linear portion of the SSC to discharge relationship. Due to the lack of information about the SSC of higher magnitude discharge events, we assumed linearity throughout the relationship. It is likely that this assumption underestimates the SSC for high magnitude discharge events. This underestimation may be partially balanced out by the fact that the data collected for peak events only included a single vertical in the center of the channel which may result in a higher assumed sediment concentration than if integrated over the entire cross-section. Rating curves were also developed for the Valencia and Spreckels Bridge sites to compare the differences in SSC with discharge at those sites. They



were not used to generate estimated long-term sediment yields due to the lack of a long-term hydrologic data set.

To calculate a long-term sediment yield for the County Park site, streamflow data for USGS gage #11159700 and #11159700 were downloaded from the web. The 1972 to 1985 record was extended back to 1959 by using the overlapping 1972 data to develop a relationship between the two gages (*see the Hydrology and Water Quality Technical Memorandum*). The data is provided by the USGS in units of cubic feet per second. Discharge for each day was converted to liters per day and multiplied by the SSC developed from the rating curve (in milligrams per liter) to produce an estimate of the total daily suspended sediment yield (in milligrams). Daily values were then added up for each year and converted to tons. The 27 years of data from 1959 to 1985 were averaged to produce an estimate of the average suspended sediment yield per year for the portion of the Aptos Creek Watershed that occurs upstream of the Valencia Creek confluence.

The main piece of missing information is the lack of bed load data. We did not collect bedload data due to the difficulty and expense in doing so. Bed load conditions can vary considerable from one storm to the next, even given the same discharge values, so it becomes very problematic to develop a rating curve with much confidence. When lacking bed load information, it is common to estimate bed load as a percentage of suspended load. In streams with bed material dominated by coarse substrate such as gravel, cobble, and boulders, high discharge values are required to move a significant amount of material since the bed is often armored. In these cases, bed load is assumed to be approximately 10% of the suspended load. Aptos and Valencia Creek are dominated by fine and coarse-grained sand, which will move as bed load during lower magnitude events as sand waves. Because of this, we would expect bed load to be a larger proportion of the overall sediment load moving through these stream channels. To account for higher bed load movement, we have assumed that bed load would be approximately 25% of suspended load. For Valencia and Trout, this value may in fact be higher given the dominance of finer grained material.

## **2.2 – CHANNEL CONDITIONS**

Once sediment is delivered to the stream, the grain-size of the material, channel morphology, and peak streamflow duration and frequency dictate how the sediment is going to be transported and sorted through the channel system. We developed a field approach to locally quantify some of these variables in order to understand how they interact and potentially control observed habitat conditions.

### **2.2.1 – Channel Cross-sections**

Cross-sections were surveyed at all reaches established as part of the fisheries and geomorphic walk-through surveys. The cross-section locations were chosen to be representative of the reach as a whole at a location that was reasonably accessible (Figure 9). At each site, three cross-section were surveyed using an auto level, stadia rod, and measuring tape. A relative benchmark was established at each site with an elevation of 100' in order to vertically associate each of the cross-sections. The three cross-sections were spaced so as to obtain an accurate estimate of the thalweg, water surface, and bankfull slope of the channel. This required an approximate distance of 100 to 200 feet between cross-sections. The longitudinal distance between each cross-section was measured with a tape.

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### 2.2.2 – Pebble Counts

Bed material grain-size was estimated in March of 2002 at each set of cross-sections by conducting a pebble count (Wolman, 1954). Approximately 200 pebbles were sampled on depositional features within the low flow channel. Depositional features were sampled to understand the grain-size distribution of sediment that would likely be mobilized during a peak flow event. A single pebble count was conducted for each group of 3 cross-sections. From the pebble count data, D16, D50, and D84 values were calculated. These values represent the 16<sup>th</sup>, 50<sup>th</sup>, and 84<sup>th</sup>, cumulative percentile of the data, respectively, if the data is sorted from finer to larger grained material.

### 2.2.3 – Estimated Shear Stress

Shear stress is the primary hydraulic variable that is used to determine the size of bed material that can be moved and held in suspension during a particular discharge event. Shear stress is a function of water depth and water surface slope. Since depth is a variable in the calculation of shear stress, channel morphology plays an important role in determining the amount of flow that would be necessary to move a particular sediment grain from the bed. Wide channels with shallow depth will move smaller grain-sizes, given a constant flow, compared to a narrow channel that is deep. Relationships have been developed defining the critical shear stress required to move a range of grain sizes (Dunne and Leopold, 1976).

A dimensionless shear stress was calculated for each site for a range of discharges by inserting the cross-section data into a HEC-RAS model. The output from the HEC-RAS model consisted of water surface depths and slopes for each discharge event. This information was then used to calculate a dimensionless shear stress.

Once dimensionless shear stress values were calculated for each site for a range of flows, grain-sizes values that would be expected to move for each shear stress value were estimated (Dunne and Leopold, 1976). A curve was then produced for each site comparing the expected minimum diameter grain-size that would move in a given discharge event.

## 2.3 – WOODY MATERIAL DENSITIES

The occurrence of large woody material within the active channel has been shown to be positively correlated with high quality salmonid spawning and rearing habitat. Woody material improves habitat conditions by providing important roughness elements to induce pool formation, clean gravels by generating hydraulic variability, and places to hide from predators and damaging high flow events. Woody material also provides a surface and nutrient source to support macroinvertebrate communities, a preferred food source for juvenile salmonids.

During the fisheries and geomorphic walk-through surveys, we quantified woody material densities continuously along all surveyed reaches. Individual logs, rootwads, and organic debris jams were surveyed using a method outlined in the California Stream Habitat Restoration Manual developed by the California Department of Fish and Game (Flosi and Reynolds, 1998). An example of the data sheet is presented in Appendix A. Along each reach the following information was collected:

- Sample length (collected using a hip chain)
- Starting and ending point of each surveyed segment
- Rosgen channel type
- Dominant canopy vegetation
- The number of logs, rootwads, or jams that occurred within the active channel according to the following size classes:

<b>1-2' Diameter</b>	<b>2-3' Diameter</b>	<b>3-4' Diameter</b>	<b>&gt; 4' Diameter</b>	<b>Debris Jams (LDA's)</b>
Logs 6-20' in length	Logs 6-20' in length	Logs 6-20' in length	Logs 6-20' in length	# of large pieces in debris jams were estimated
Logs > 20' in length	Logs > 20' in length	Logs > 20' in length	Logs > 20' in length	
Rootwad	Rootwad	Rootwad	Rootwad	

Additional information was collected about each piece surveyed including whether the piece was dead and downed, dead and standing, or live. Live pieces were categorized into either deciduous or coniferous. Woody material data collected for each reach was compiled and the number of pieces per mile for each category was calculated to allow for comparisons between each reach. To account for the number of logs present in the debris jams, an attempt was made to integrate these data with the results for individual logs. These data are reported separately since they are not necessarily as accurate as the individual log measurements.

## 3.0 – RESULT AND DISCUSSION

### 3.1 – SEDIMENT BUDGET

#### 3.1.1 - Sediment Input (I)

The primary purpose of the sediment budget estimate that we have put together for this report is to understand the dominant erosion processes that are occurring in the watershed, what the relative magnitude of each of those might be, and which portions of the watershed are contributing to the overall sediment budget. It is not intended to quantify and understand the fate of each grain of sand being delivered to the channel. Instead, it is meant to direct attention to specific sources as a way to focus future efforts to control erosion in the watershed in an intelligent and informed way.

Table 4 lists the estimated sediment yield for the Aptos Creek Watershed by sediment source and location. The total estimated sediment yield for the Aptos Creek Watershed is approximately 60,500 tons/year. Averaged over the whole watershed, the expected yield is approximately 2,465 tons/mi<sup>2</sup>/year. Each subwatershed has an expected yield of 2,670, 1,940, 2,380, and 2,300 tons/mi<sup>2</sup>/year for Aptos, Mangels, Trout, and Valencia, respectively. These values fall within the expected range of sediment yields generated for other watersheds in coastal California (Table 5). Sediment yields from other forested watersheds range from 5,486 tons/mi<sup>2</sup>/year in Redwood Creek, Humboldt County, where extensive logging and land use impacts have occurred, to 680 tons/mi<sup>2</sup>/year on the South Fork of Caspar Creek, an unlogged subwatershed in a paired watershed study.



Mass wasting on Aptos and Valencia Creeks. Both are chronic sediment sources. The one on the left appears to be natural, caused by undercutting in the outer bend of a meander. The photo on the right is clearly related to development occurring at the top of the hillslope.

	Sub-Watershed	Feature Length (miles)	Erosion Rate (tons/mi <sup>2</sup> /yr)	Delivery Efficiency	Sediment Delivery Rate to Streams (tons/mi/yr)	Sediment Yield (tons/yr)	Totals by Erosion Type (tons/yr)	Total Sediment Yield (tons/yr)	Total Sediment Yield (tons/mi2/yr)		
Inner Gorge Paved Roads	Aptos Creek	3.4	78.1	100%	78.1	263	1,293	60,521	2,465		
	Mangels Gulch	2.0	78.1	100%	78.1	159					
	Trout Gulch	1.8	78.1	100%	78.1	143					
	Valencia Creek	9.3	78.1	100%	78.1	728					
Inner Gorge Dirt Roads	Aptos Creek	1.6	600	100%	600	560	581				
	Mangels Gulch	0.1	600	100%	600	21					
	Trout Gulch	None Mapped									
	Valencia Creek	None Mapped									
Hillslope Paved Roads	Aptos Creek	23.6	78.1	42%	33	773	4,052				
	Mangels Gulch	13.8	78.1	42%	33	452					
	Trout Gulch	14.1	78.1	42%	33	463					
	Valencia Creek	72.1	78.1	42%	33	2364					
Hillslope Dirt Roads	Aptos Creek	6.0	600	42%	252	1523	1,566				
	Mangels Gulch	None Mapped									
	Trout Gulch	None Mapped									
	Valencia Creek	0.2	600	42%	252	43					
Bank Erosion	Aptos Creek	24.7	70	100%	70	1729	8,184				
	Mangels Gulch	2.1	170	100%	170	357					
	Trout Gulch	6.0	327	100%	327	1962					
	Valencia Creek	21.1	196	100%	196	4136					
	Sub-Watershed	Feature Area (Sq. miles)	Erosion Rate (tons/mi <sup>2</sup> /yr)	Delivery Efficiency	Sediment Delivery Rate to Streams (tons/mi <sup>2</sup> /yr)	Sediment Yield (tons/yr)					
Mass Wasting	Aptos Creek	11.6	7996	20%	1599	18538	26,772				
	Mangels Gulch	1.2	1605	20%	321	395					
	Trout Gulch	2.3	2316	20%	463	1078					
	Valencia Creek	9.4	3593	20%	719	6761					
Urban and Rural Lands	Aptos Creek	11.6	1548	42%	650	7536	18,073				
	Mangels Gulch	1.2	1935	42%	813	999					
	Trout Gulch	2.3	1935	42%	813	1892					
	Valencia Creek	9.4	1935	42%	813	7646					

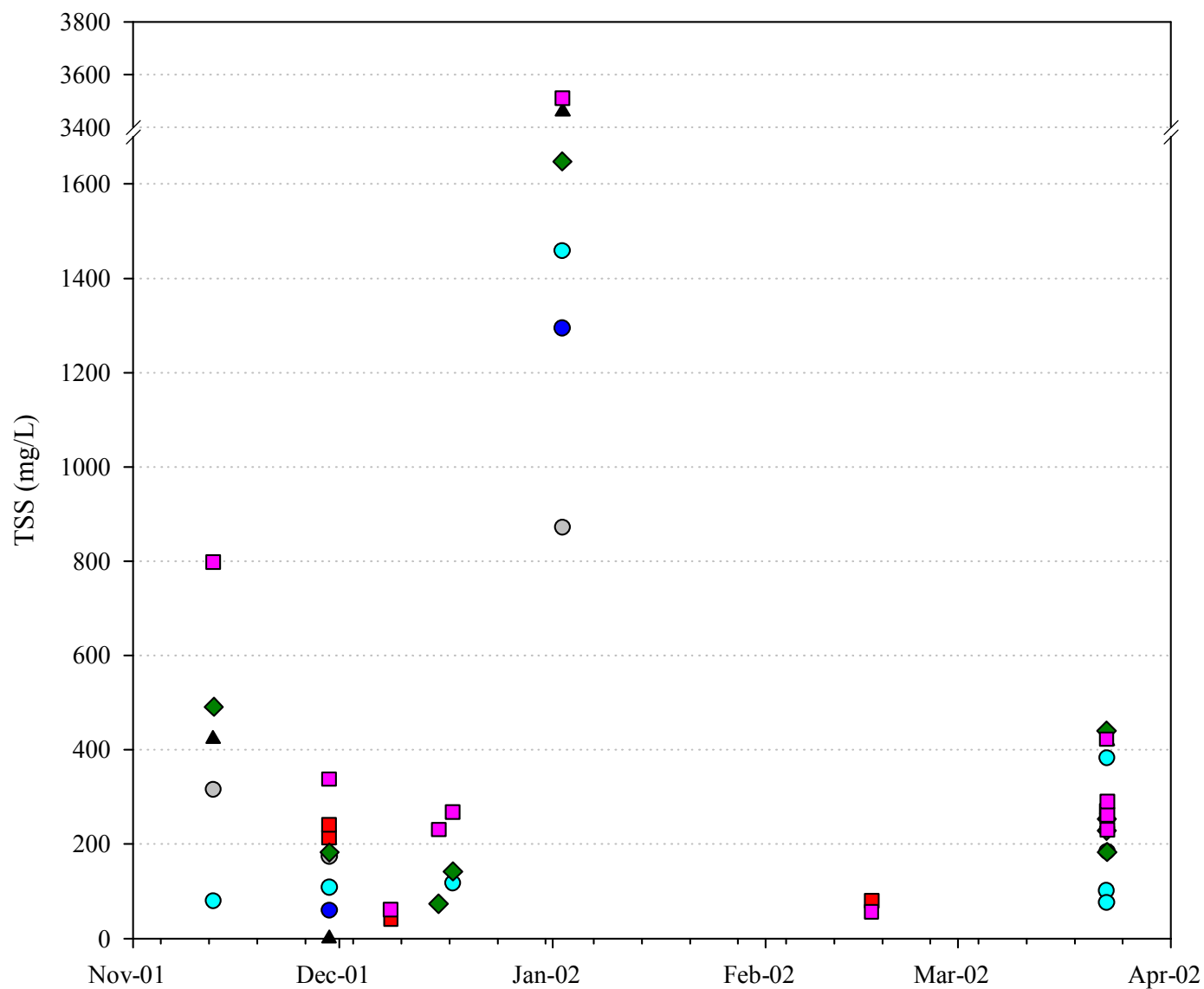
**Table 4:** Estimated sediment yield for each erosion source, by major subwatershed.

**Table 5 :** Published Annual Sediment Yields for the Coast Ranges of California.  
 Note : Table adapted from the Zayante Area Sediment Source Study (Swanson and Dvorsky, 2001).

<b>River/Stream</b>	<b>Sediment Yield (tons/mi<sup>2</sup>)</b>	<b>Watershed Area (mi<sup>2</sup>)</b>	<b>Period of Record</b>	<b>County</b>
Redwood <sup>1</sup> Creek	4750	278	1954-1997	Humboldt
Redwood <sup>1</sup> Creek	5485	278	1954-1997	Humboldt
Garcia River	1400	114	1952-1997	Mendocino
South Fork <sup>2</sup> Caspar Creek	680	1.83	1962-1998	Mendocino
North Fork <sup>2</sup> Caspar Creek	1111	1.64	1962-1998	Mendocino
Navarro River	1200	303	1980-1988	Mendocino
Arroyo Grande Creek	380	13.5	1943-1972	San Luis Obispo
Lopez Creek	1800	21.6	1943-1972	San Luis Obispo
Santa Rita Creek	1100	18.2	1943-1972	San Luis Obispo
Uvas Creek	1337	21	1967-1969	Santa Clara
Coyote Creek	813	109	1967-1969	Santa Clara
Arroyo Valle	1000	147	1967	Contra Costa
Colma Creek	6768	10.8	1966-1970	San Mateo
Little Santa Anita Canyon	22262	2.4	1938, 43, 52	Los Angeles
Pickens Canyon	43069	1.7	1938, 43, 54	Los Angeles

1. Researchers studying the same system reported different sediment yields. This outlines the uncertainty associated with estimating erosion rates and the potential range of assumptions made to arrive at a basin-averaged sediment yield.
2. Paired watershed study compared logged versus unlogged land.

Surprisingly, the sediment budget results suggest that Valencia had a lower per unit sediment yield than Aptos despite the fact that Valencia is the most turbid tributary during peak discharge events (Figure 11) and has a bed primarily composed of sand that overwhelms the stream and contributes to degradation of aquatic habitat. The sediment budget results may not completely describe what is occurring both in Valencia and Trout. What is missing from our sediment budget analysis is an estimate of the amount of sediment that has historically been delivered to the channel and is in the process of being reworked and remobilized. Fine sediment deposits stored in the channel and in the floodplain, potentially due to turn of the century logging, may be remobilized under most flow conditions, due to the sandy nature of the deposits, and result in higher sediment yields than would be expected based on our estimate of erosion from hillslopes and banks.



- ▲ Trout Gulch
- Mangel's Gulch
- Valencia Creek (Polo Fields)
- Aptos Creek (Steel Bridge)
- Aptos Creek (County Park)
- ◆ Mainstem (Spreckels)
- Valencia Creek (Elementary School)



Shallow sandy bed on Valencia Creek.

Valencia, Trout, and Mangels may also be significantly impacted by recent urbanization of the watershed which has had a cumulative impact on the conditions in the channel. As watersheds urbanize, an increasing percentage of the land surface becomes impervious to rainfall due to more roads, rooftops, and driveways. The increase in impervious surfaces creates a hydrologic regime that is flashier, with higher peak flow values. This is especially evident during low magnitude precipitation events. In undisturbed watersheds, low magnitude precipitation events produce very little runoff due to soil storage and percolation to groundwater. In urbanized watersheds, even small amounts of rainfall produce a significant amount of runoff from impervious surfaces that are delivered quickly to stream channels. This has been shown to increase bank erosion (Booth and Henshaw, 2001) and create unstable geomorphic conditions as the channel attempts to adjust to a new hydrologic regime.

This process is magnified as the watershed becomes increasingly urbanized. There is little time for the channel to adjust to changing hydrologic conditions if those conditions are continually changing. When a channel is in a continual state of change, a massive episodic disturbance could result in catastrophic consequences. According to anecdotal evidence, it appears that such a scenario occurred on Valencia and Trout Creeks in the wake of the 1982 flooding event. Prior to 1982, the Valencia and Trout Creek watershed were experiencing periods of fairly rapid urbanization, especially during the 1970's. At that time, very few people considered the repercussions development would have on the stream channels and aquatic habitat conditions. Fisheries conditions in Valencia appeared to remain fairly stable, despite the impacts occurring in the watershed. In 1980, a comprehensive estimate of steelhead numbers and habitat quality was conducted throughout Santa Cruz County (Smith, 1982). The data suggest that Valencia supported a good steelhead fishery. In fact, Valencia had some of the highest densities of juvenile steelhead in Santa Cruz County.

In the winter of 1982 a series of storms battered the California coast, causing extensive damage throughout Santa Cruz County. These storms may have been the “straw that broke the camels back” for Valencia Creek, an event that the system has yet to recover from. Eyewitnesses reported severe damage to Valencia Creek that included complete unraveling of the banks of the lower stream channel and 2 to 5 feet of aggradation that consisted almost entirely of sand-sized material (Smith, personal communication). If this is true, it is likely that the system is still adjusting to such a massive sedimentation event while at the same time reacting to increased pressure from urbanization and a continually changing hydrologic regime. If we were to assume that 3 feet of aggradation occurred over a total distance of 7 miles along the mainstem reaches of Valencia and Trout Creek, with an average floodplain width of 20 feet (assuming sediment deposited directly in the channel was removed soon after the aggradation event), there would be approximately 98,000 tons of sediment available for transport. That amount is approximately 4 times the estimated volume of sediment delivered to Valencia and Trout Creeks from all other sources combined (Table 6). This sediment source should be investigated in the future in order to refine our preliminary sediment budget estimates.

**Table 6:** Estimates of natural versus anthropogenic sediment yields from Aptos Creek Watershed.

<b>Subwatershed</b>	<b>Sediment Yield (tons/yr)</b>	<b>Sediment Yield (tons/mi<sup>2</sup>/yr)</b>	<b>Natural (tons/yr)</b>	<b>Athropogenic (tons/yr)</b>
Aptos	30,922	2,668	22,581	8,341
Mangels	2,383	1,938	1,507	875
Trout	5,538	2,379	2,004	3,534
Valencia	21,678	2,304	8,609	13,068

The sediment budget numbers can also be manipulated to obtain a rough estimate of the amount of material that is being delivered to the stream channel from either natural or anthropogenic sources (Table 6). This requires some knowledge of the land uses occurring in a particular subwatershed and an educated estimate of the percent of the total yield that is expected to be caused by human impacts, as opposed to naturally occurring erosion processes. Table 7 outlines the percentages that were determined to be appropriate for each source for each individual watershed. Sediment delivered to the channel off of roads was assumed to be entirely anthropogenic, whereas the other categories were proportioned according to observed land use impacts in the watershed. Aptos was assumed to be the least influenced by human interactions to the landscape. Much of the watershed is protected within a state park and a large number of the landslides occurring within the watershed have been documented to be a result of the Loma Prieta earthquake.

**Table 7:** Percent of erosion that was considered to be anthropogenic for each erosion source.

<b>Subwatershed</b>	<b>Erosion from Roads</b>	<b>Bank Erosion</b>	<b>Mass Wasting</b>	<b>Urban and Rural Lands</b>
Aptos	100%	30%	30%	30%
Mangels	100%	50%	50%	50%
Trout	100%	70%	60%	80%
Valencia	100%	70%	60%	80%

The results from this rough analysis suggest that a significant proportion of the sediment being delivered to Trout and Valencia Creek are due to anthropogenic sources and could potentially be reduced through better erosion control practices, implementation of Best Management Practices (BMP's) that address specific problems that occur within those watersheds, and potentially, stabilization of hydrologic conditions by increasing soil infiltration and retaining or detaining runoff from impervious surfaces. Sediment reductions

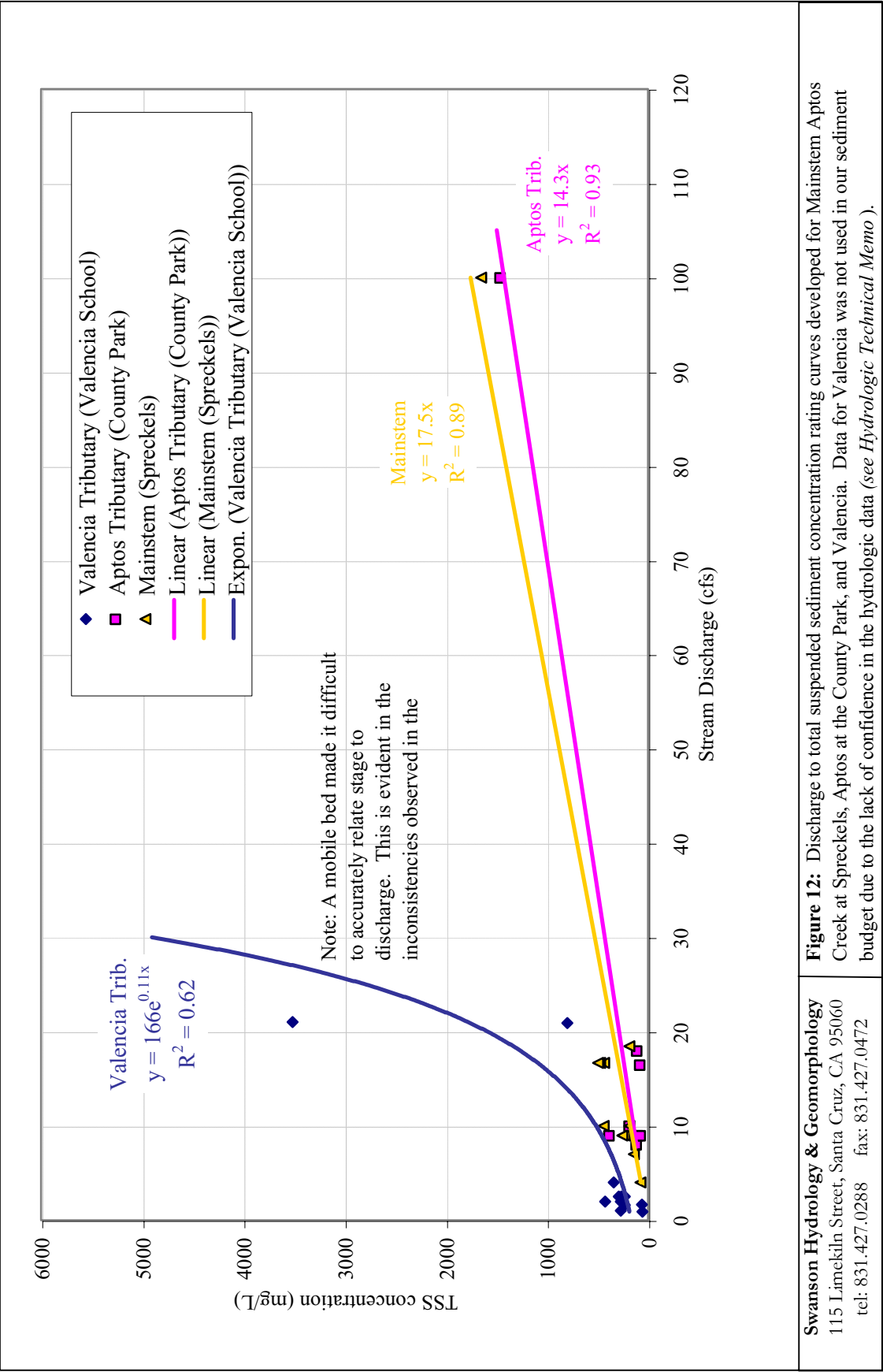
on the order of 20 to 50% of existing yields could improve aquatic habitat conditions considerably if Aptos Creek is used as a model for habitat conditions in Valencia. The upper watershed of Aptos Creek provides high quality spawning and rearing habitat for salmonids despite a significant amount of fine sediment being delivered to the channel. It is likely that many of the sources in Aptos are episodically, as opposed to chronically, delivered to the channel, which allows those sediments to be flushed from the system on subsequent storm events. Aptos also appears to have fewer overbank deposits as compared to Valencia. These deposits become mobilized under a wide range of discharges, creating the conditions observed in the lower portions of Trout and Valencia.

Despite the high estimated sediment yields in Aptos Creek, episodic delivery of material, a stable hydrology, and a proper functioning channel, allow for adequate flushing and sorting of the delivered material to maintain aquatic habitat. The important difference between conditions in Aptos and conditions in Valencia appears to be the source of the sediment and the capacity of the system to handle that sediment. Sources in Aptos primarily are derived from landslide material. In the case of a landslide, sediment is delivered episodically. Historic fisheries data (*discussed in the Fisheries Technical Memorandum*) suggest that Aptos is periodically inundated by large amounts of sediment that have devastated the fishery. Fortunately the system has recovered as subsequent storms flush out these sediments. In the absence of chronic inputs of fine material, the system is resilient and can recover. Valencia appears to experience the same episodic events, but unlike Aptos, has been unable to recover due to a combination of factors including geologic conditions, extensive fine-grained overbank deposits, and chronic fine sediment inputs from sources such as bank erosion or headcutting of first order tributaries. The rate of bank erosion in Valencia Creek, as estimated from the 2002 survey, was approximately 3 times greater than Aptos. The rate in Trout was almost 5 times greater than in Aptos.

### **3.1.2 - Sediment Output (O)**

Since an extended streamflow record is limited to Aptos Creek, upstream of the confluence with Valencia, we were only able to estimate the sediment output term (O) for that portion of the watershed. The rating curve developed for the Aptos Creek site is shown in Figure 12. The rating curve was used along with the historic streamflow record from Aptos Creek (1959 to 1985) to estimate suspended sediment transported through Aptos Creek (Table 8). Bedload was assumed to be 25% of the suspended sediment load. The results suggest that approximately 25,000 tons of sediment is being transported through Aptos Creek upstream of the confluence with Valencia. This value is fairly close to the 30,900 tons of sediment that was estimated as being delivered to Aptos Creek from the watershed.

Considering that a portion of the sediment eroded from the watershed is coarser material that may be stored in gravel and cobble bars (Table 9) and a portion is stored behind the extensive logjams that occur in the upper watershed, we feel these numbers correspond fairly well. Additionally, the rating curve, developed to estimate the suspended portion of the sediment load, is likely to underestimate the amount of sediment being moved during larger events since our sampling was limited to fairly low magnitude events. Generally, we feel comfortable with the results given the amount of data available to construct the sediment budget and the assumptions that needed to be made to arrive at a final estimate. It is not uncommon for sediment budget calculations to have a significant margin of error given the challenges inherent in sediment budget calculations and a requirement to make general assumptions regarding the processes that are at work in the watershed controlling both delivery and transport of sediment to and through the system (Reid and Dunne, 1996).



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**Figure 12:** Discharge to total suspended sediment concentration rating curves developed for Mainstem Aptos Creek at Spreckels, Aptos at the County Park, and Valencia. Data for Valencia was not used in our sediment budget due to the lack of confidence in the hydrologic data (see *Hydrologic Technical Memo* ).

**Table 8:** Estimated suspended and bedload transport through Aptos Creek based on field measurements and historic streamflow records. Also shown is the estimated sediment input for the Aptos subwatershed based on the sediment budget analysis.

Water Year	Annual Suspended Sediment Yield		Suspended + Bedload (bedload estimated as 25% of Suspended)
	in grams	in tons	in tons
<b>1959</b>	3.23E+09	3,562	4,453
<b>1960</b>	1.38E+09	1,525	1,906
<b>1961</b>	4.31E+07	48	59
<b>1962</b>	5.18E+09	5,708	7,135
<b>1963</b>	5.49E+10	60,532	75,665
<b>1964</b>	7.82E+08	862	1,078
<b>1965</b>	1.32E+10	14,527	18,159
<b>1966</b>	1.32E+08	146	182
<b>1967</b>	2.48E+10	27,322	34,153
<b>1968</b>	1.85E+09	2,041	2,551
<b>1969</b>	2.99E+10	32,912	41,140
<b>1970</b>	2.48E+10	27,357	34,196
<b>1971</b>	1.11E+09	1,219	1,524
<b>1972</b>	9.92E+07	109	137
<b>1973</b>	2.82E+10	31,108	38,885
<b>1974</b>	1.09E+10	11,980	14,975
<b>1975</b>	3.86E+09	4,257	5,322
<b>1976</b>	5.11E+07	56	70
<b>1977</b>	2.20E+07	24	30
<b>1978</b>	1.61E+10	17,724	22,155
<b>1979</b>	1.39E+09	1,535	1,919
<b>1980</b>	3.26E+10	35,904	44,879
<b>1981</b>	1.07E+09	1,182	1,477
<b>1982</b>	1.81E+11	199,907	249,884
<b>1983</b>	5.79E+10	63,852	79,816
<b>1984</b>	7.21E+09	7,955	9,943
<b>1985</b>	1.49E+09	1,638	2,047
<b>Average</b>	<b>1.86E+10</b>	<b>20,555</b>	<b>25,694</b>
<b>Estimated Sediment Input to Aptos</b>			<b>30,813</b>

**Table 9:** Erosion sites sampled within the Aptos Creek watershed. Samples were collected using a shovel and dried and seived in the lab. Samples are meant to describe the grain-size distribution from characteristic erosion sources found in the watershed.

Sample ID	Sub-Watershed	Cause of Erosion	Sieve # / Sieve Opening				
			12	16	20	30	>30
			1.7mm	1.18mm	.85mm	.6mm	<.6mm
1	Valencia Creek	Landslide	0	0	<11	50	50
2	Valencia Creek	Roadside Ditch	2	1	2	20	75
3	Valencia Creek	Roadside Ditch	1	0	1	25	73
4	Valencia Creek	New Development	5	0	0	5	90
5	Valencia Creek	Tilled Orchard	5	1	2	17	75
6	Valencia Creek	Landslide	3	0	2	15	80
7	Valencia Creek	New Development	1	1	3	25	70
8	Valencia Creek	Dirt Road	10	10	12	13	55
9	Valencia Creek	Road Cut	1	1	3	10	85
10	Valencia Creek	Road Drainage	1	0	0	9	90
11	Valencia Creek	Tilled Orchard	1	0	0	0	99
12	Valencia Creek	Dirt Road	10	5	15	25	45
13	Valencia Creek	Landslide	20	5	5	20	50
14	Valencia Creek	Road Cut	2	0	0	8	90
15	Valencia Creek	Dirt Road	65	1	2	7	25
16	Valencia Creek	New Development	3	1	1	10	85
17	Trout Creek	Perched Culvert	5	1	3	6	85
18	Trout Creek	Road Cut	0	0	5	10	85
19	Trout Creek	Annual Tributary	2	1	5	45	47
20	Trout Creek	Perched Culvert	5	0	0	45	50
21	Trout Creek	Bank Erosion	2	1	2	60	35
22	Trout Creek	Incised Tributary	1	<1	1	10	88
23	Trout Creek	Culvert/ Tributary	0	0	1	80	19
24	Trout Creek	Bank Erosion/ Landslide	1	1	2	5	91
25	Valencia Creek	Road Cut	2	0	3	5	90
26	Valencia Creek	Exposed Area	5	0	0	5	90
27	Valencia Creek	Bank Erosion	10	2	3	15	70
28	Valencia Creek	Bank Erosion	0	0	0	5	95
A-1	Aptos Creek	Exposed area	25	2	3	10	60
A-2	Aptos Creek	Landslide/ timber	<1	<1	10	25	65

**Table 9:** Erosion sites sampled within the Aptos Creek watershed. Samples were collected using a shovel and dried and seived in the lab. Samples are meant to describe the grain-size distribution from characteristic erosion sources found in the watershed.

Sample ID	Sub-Watershed	Cause of Erosion	Sieve # / Sieve Opening				
			12	16	20	30	>30
			1.7mm	1.18mm	.85mm	.6mm	<.6mm
A-3	Aptos Creek	Landslide	40	5	5	10	40
A-4	Aptos Creek	Runoff	15	5	20	40	20
A-5	Aptos Creek	Exposed shoulder	60	<1	5	10	25
A-6	Aptos Creek	Bank Erosion	<1	<1	<1	<1	97
A-7	Aptos Creek	Bank Erosion	28	2	10	40	20
A-8	Aptos Creek	Gutter/ ditch	<1	<1	<1	5	95
A-9	Aptos Creek	Landslide/ road	5	<1	10	20	65
A-10	Aptos Creek	Runoff/ gutter	0	0	5	10	85
A-11	Aptos Creek	Culvert	1	0	1	13	85
A-12	Aptos Creek	Road cut	0	<1	10	15	75
A-13	Aptos Creek	Runoff	10	5	10	25	50
A-14	Aptos Creek	Culvert	10	5	5	10	70
A-16	Aptos Creek	Roadcut	20	5	5	10	60
M-1	Mangels Gulch	Road cut	55	<1	5	10	30
M-2	Mangels Gulch	Road cut	<1	<1	10	20	70
M-3	Mangels Gulch	Dumped	20	<1	10	25	45
M-4	Mangels Gulch	Landslide/ roadcut	8	2	20	35	35
M-6	Mangels Gulch	Culvert	35	<1	10	25	30
M-7	Mangels Gulch	Construction	20	2	3	15	60
M-8	Mangels Gulch	Exposed area	10	2	3	25	60

Though it is difficult to estimate the magnitude of the potential error associated with the sediment budget calculations, it is appropriate to discuss the level of confidence we have in the numbers and the potential direction of error. This discussion is likely to be most useful if it is discussed by source.

*Roads: Underestimated; Magnitude Unknown.* The erosion rate for roads was obtained directly from the CDF study for the Soquel Demonstration Forest (Cafferata and Poole, 1993). In terms of estimating a long-term sediment erosion rate from roads, it is likely that the rates derived for Soquel may be an underestimate. A significant proportion of the sediment yield from roads may be associated with failure of road fill prisms and culverts during low probability, high magnitude storm events. The other portion is chronic rill and gully erosion associated with road surfaces, drainage, etc. Given the short timeframe of the CDF study, it is likely that they did not measure these episodic events and may be underestimating the contribution of sediment from roads. In addition to this, our GIS road network was incomplete and did not include private or THP (Timber Harvest Plan) roads.

*Bank Erosion: Reasonably Confident; Slight Underestimation.* Though erosion rates are estimated due to unknowns about erosion volume and failure dates, we feel the numbers are fairly accurate and reflect observed conditions. Total sediment volume may be underestimated since we did not walk some of the lower order tributaries. These tributaries may prove to be a source of a significant quantity of sediment since they would be directly impacted by increases in impervious surfaces that result in gully formation and channel incision.

*Mass Wasting: Reasonably Confident; Direction of Error Unknown.* We had the advantage of a high quality dataset from Nisene Marks. The big question relates to extrapolation of this data to the urbanized watersheds of Mangels, Trout, and Valenica. A more rigorous approach would include a sensitivity analysis that attempts to relate landslide occurrence with physical characteristics of the landscape including lithology, slope, etc.

*Urban and Rural Lands: Lack of Confidence; Magnitude of Error Unknown.* Similar to the road erosion estimates, the erosion rate from rural and urban lands were obtained directly from the CDF study (Cafferata and Poole, 1993), which consists of a brief study of a process that is both chronic and episodic. Unlike development of road erosion rates, estimating erosion from urban and rural lands would be problematic, regardless of the quality of data available. These erosion sources are distributed across the landscape and are therefore difficult to quantify without a comprehensive, long-term study that includes study plots distributed across the range of landscape conditions. In the absence of such a dataset, the CDF study is the best available data. Further refinement of the estimates could be accomplished by dividing the landscape into distinct land uses including timber harvest areas, orchards, rural residential, and urban and assigning erosion rates to each.

*Orverbank Deposits: Unknown.* We feel this is a significant source of sediment, especially in Valencia Creek, that was not quantified as part of this study. Further studies should refine this element by quantifying the amount of sediment that is stored in the these deposits and their accessibility to low to moderate flow events.

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*Sediment Output: Reasonably Confident; Underestimated.* The output term of the sediment budget equation is important for calibration of the source assessment results. Considering the limited amount of data we had to work with, our results represent the best approximation and fall within the expected error of the source assessment results. We feel the value may be slightly underestimated since we did not observe, nor sample suspended sediment concentrations during high magnitude runoff events. There is also a gap in our understanding of discharge conditions in Valencia Creek which appears to have both a higher suspended and bedload contribution.

## **3.2 – CHANNEL CONDITIONS**

### **3.2.1 - Substrate Conditions**

Channel conditions throughout the watershed are clearly shown in the pebble count results available at monitoring sites throughout the watershed (Table 10; Appendix B; Figures 13-16). Fine sediment is present throughout the watershed as evidence by the low D16 values and high percentage of fine material. The most degraded reaches include lower Aptos, below the confluence with Valencia, Trout, Mangels, and Valencia.

The cross-section and pebble count surveys were conducted in late winter following a winter that lacked a significant number of high flow events. Regardless, the data are representative of late winter conditions with higher percentages of coarser sediment than was observed to be present during the summer months when much of coarser substrate is buried under sand deposits. We observed this situation during several other field visits following storm events. Small pools are carved out near roughness elements and coarser material is exposed on the bed, only to be filled with sand-sized material as waves of fine-grained material moves through the system.


This phenomenon is evident in the calculations that were made to estimate the size of sediment that can potentially move under a range of flow conditions based on channel geometry and grain-size information available for each cross-section site. In lower Aptos, Mangels, Trout, and a few reaches of Valencia, the bed is mobile during even low to moderate discharges. This information clearly shows the difficulty of maintaining high quality spawning and rearing habitat in these tributaries under current conditions. A highly mobile bed, combined with a significant quantity of fine-grained sediment moving through the stream channel, precludes use of the stream channel for successful spawning. Even if spawning were to occur, rearing habitat appears to be limited.

### **3.2.2 – Woody Material**

The quantity of woody material within Aptos Creek is probably much lower than what it was historically but the density of wood appears to be comparable to the amount of wood found in tributaries to the San Lorenzo River such as Carbonera, Lower Zayante, Bear, and Boulder Creeks (Dvorsky, Alley, and Smith, 2002), except in selected reaches (Table 11; Figures 17-19). Woody material appears to be lacking in the lower reach of Aptos downstream of the Valencia confluence, which is probably due to local residences removing the wood out of fear of flooding or bank erosion.

## Legend

### Aptos Creek Watershed

 Rivers and Streams

### Pebble Count D16

Grain Size in mm

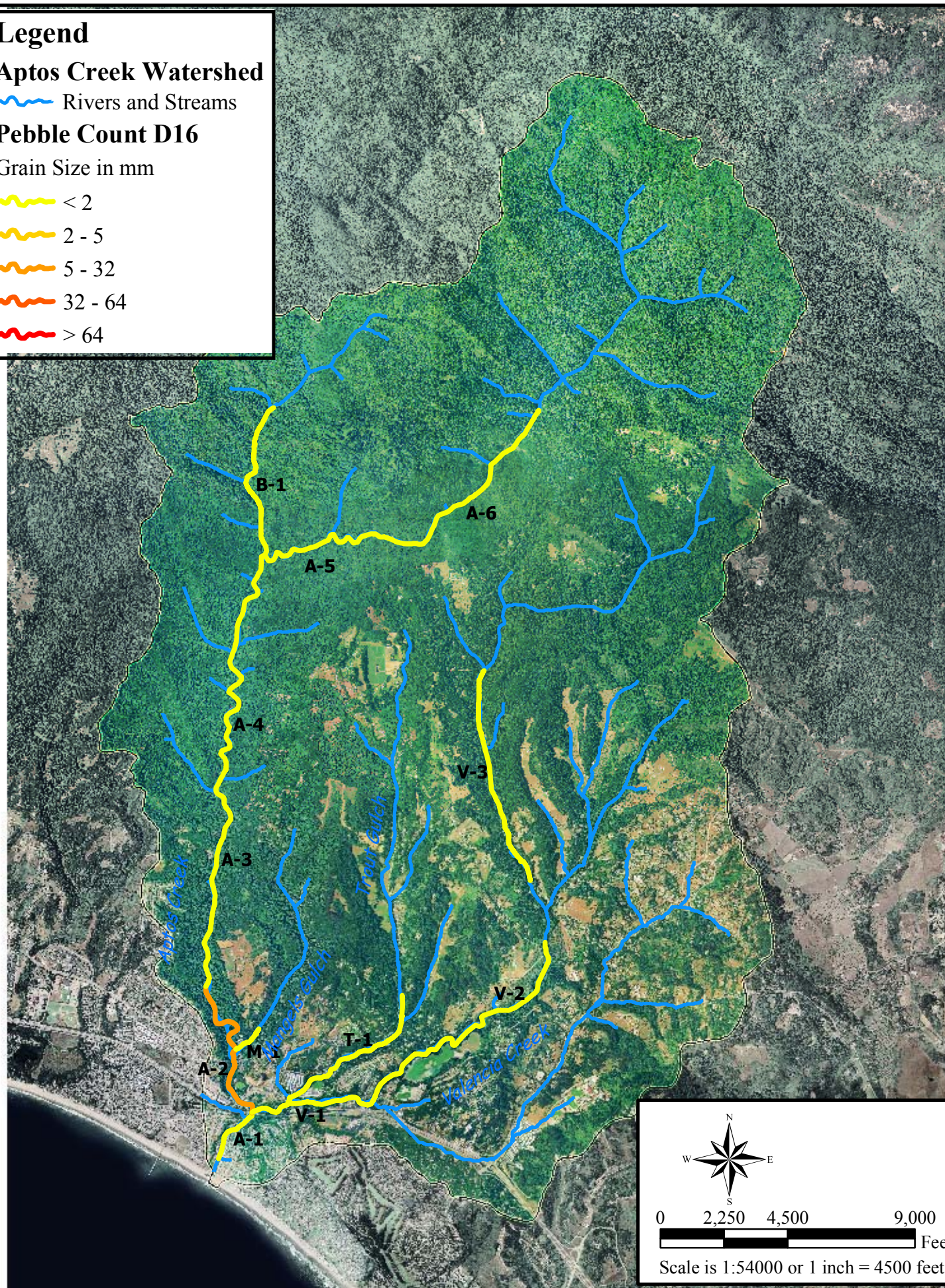
 < 2

 2 - 5

 5 - 32


 32 - 64

 > 64



## Legend

### Aptos Creek Watershed

 Rivers and Streams

### Pebble Count D50

Grain Size in mm

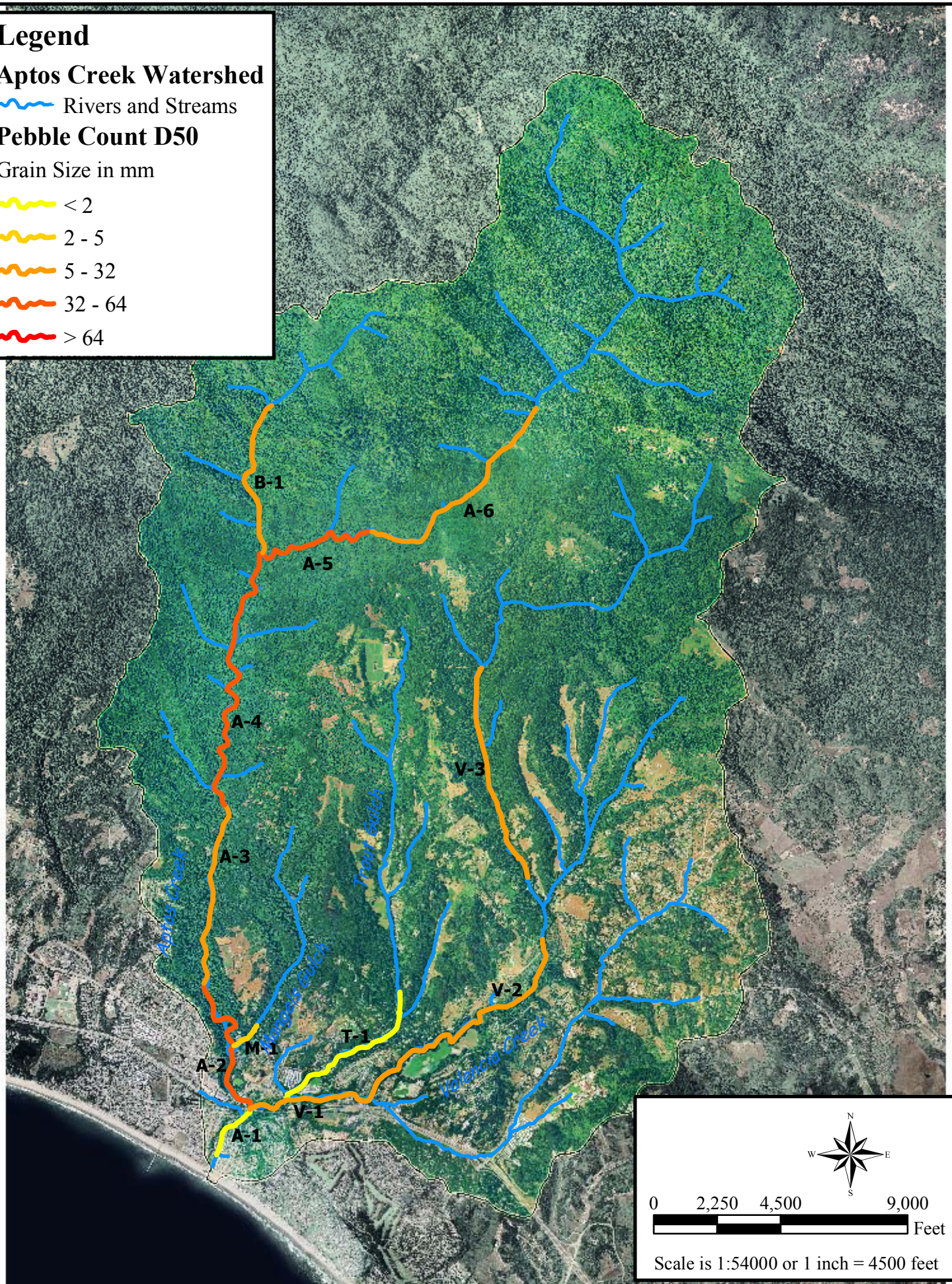
 < 2

 2 - 5

 5 - 32

 32 - 64

 > 64




0 2,250 4,500 9,000  
Feet

Scale is 1:54000 or 1 inch = 4500 feet

## Legend

### Aptos Creek Watershed

 Rivers and Streams

### Pebble Count D84

Grain Size in mm

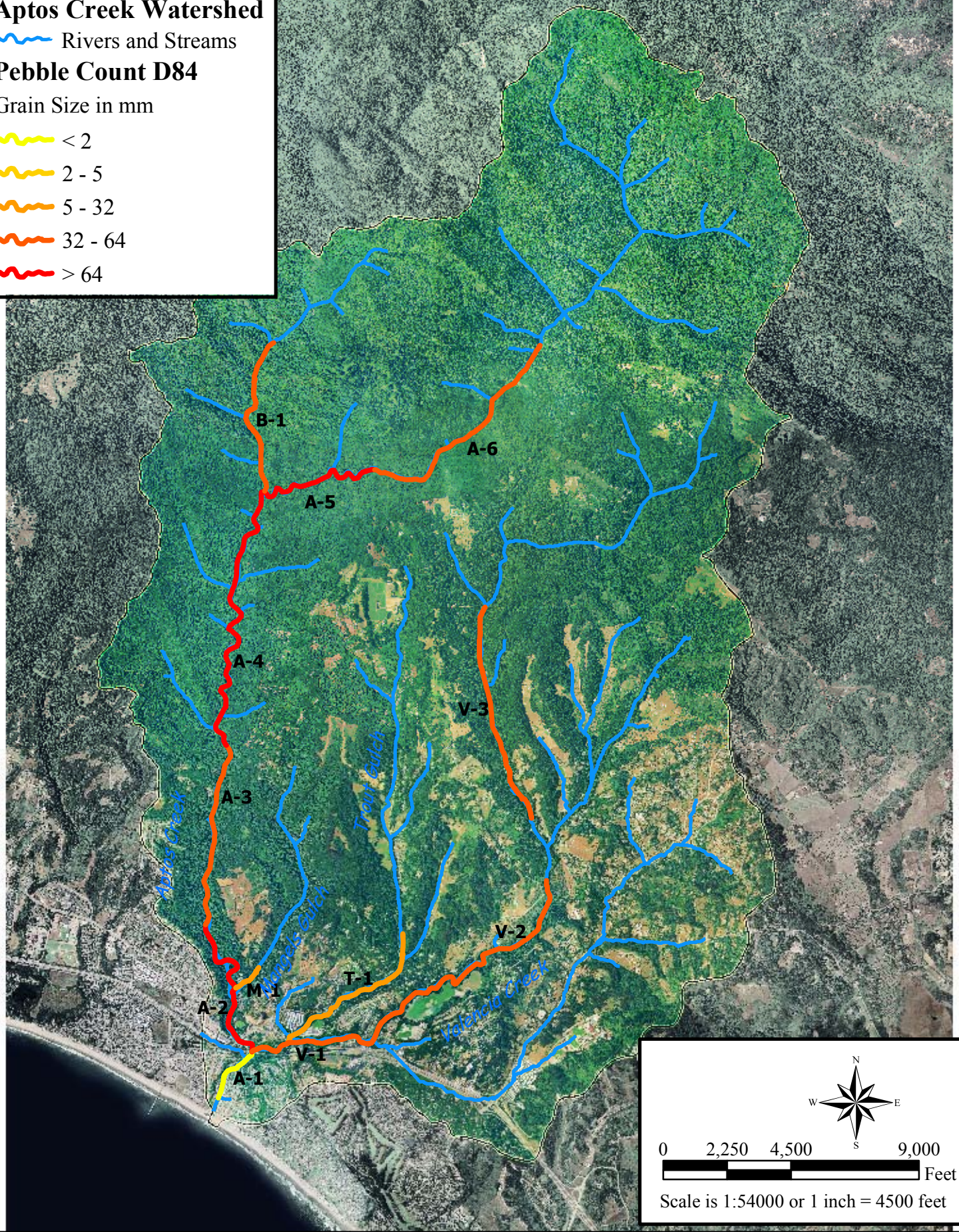
 < 2

 2 - 5

 5 - 32


 32 - 64

 > 64




## Legend

### Aptos Creek Watershed

 Rivers and Streams

### Percent Fines based on Pebble Count

Percent by Reach

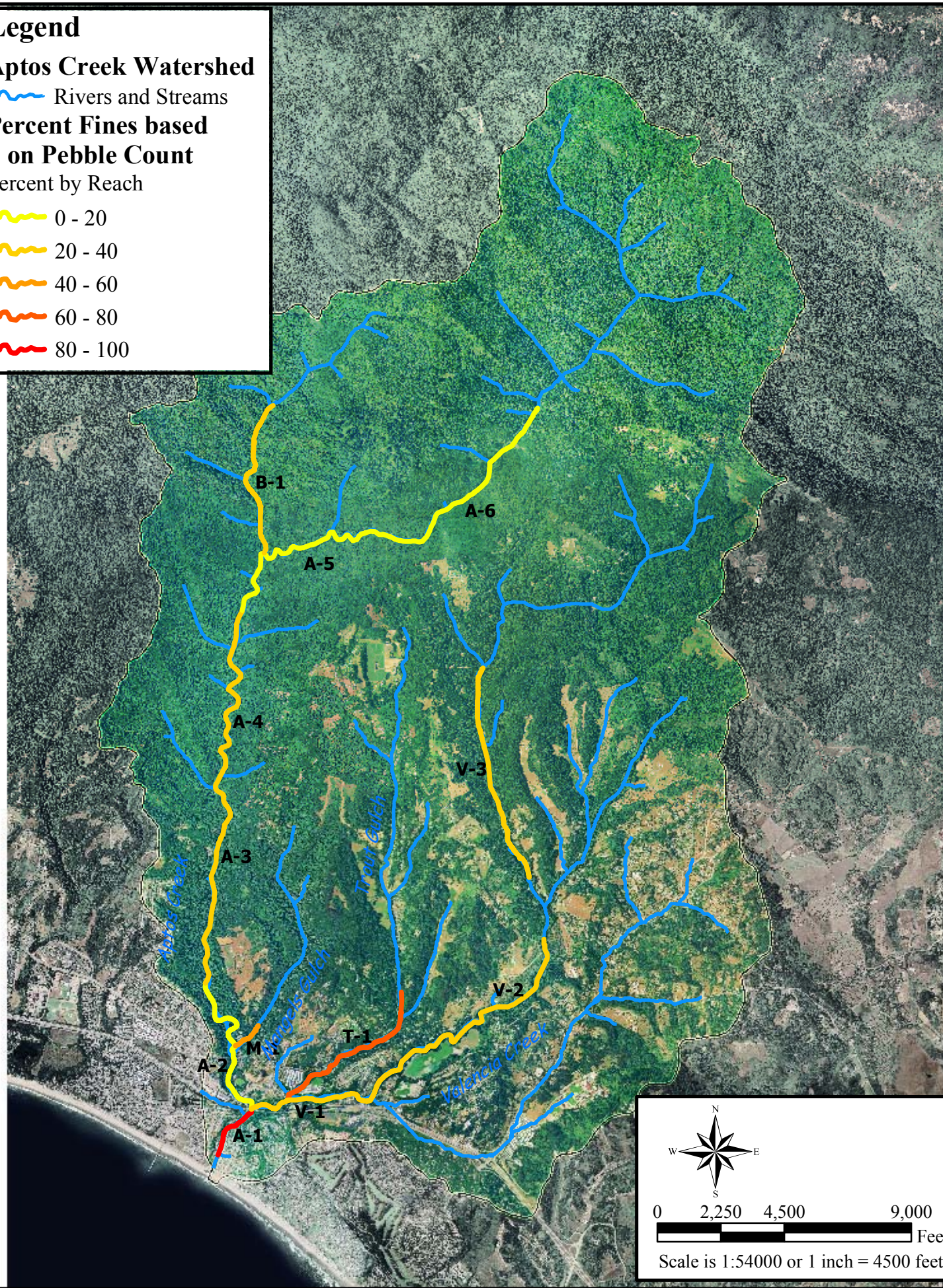
 0 - 20

 20 - 40

 40 - 60

 60 - 80

 80 - 100



**Table 10:** Pebble count results for monitored cross-sections throughout the Aptos Creek Watershed expressed as a percentile of the sample. An approximate flow at which the 50<sup>th</sup> percentile of the sample is mobilized is also shown based on hydraulic modeling results. A more detailed presentation of the results is available in Appendix B. Pebble counts were conducted between 3/20 and 3/25/2002 and may reflect a bias towards coarseness or a “best-case” scenario. Bed conditions may in fact be more sandy during late spring, summer, and fall. The results for reach A-2 may constitute an outlier associated with the site selection. Depositional features may have been absent at this site.

Reach-ID	D16	D50	D84	Percent Fines (< 2 mm)	Approximate flow required to move D50
A-1	1.0	1.0	1.0	98	3 cfs
A-2	30.0	55.0	100.8	0	> 200 cfs
A-3	1.0	11.0	46.2	30	35 cfs
A-4	1.0	34.5	77.1	29	175 cfs
A-5	1.0	55.5	115.2	19	130 cfs
A-6	1.0	25.0	58.0	17	5 cfs
B-1	1.0	22.0	62.3	26	40 cfs
V-1	1.0	10.0	40.2	39	10 cfs
V-2	1.0	15.5	52.5	37	30 cfs
V-3	1.0	9.5	40.3	39	3 cfs
T-1	1.0	1.0	6.2	77	< 1 cfs
M-1	1.0	3.0	16.0	49	< 1 cfs

Historically in Santa Cruz Mountain streams, an abundant supply of large, long-lasting redwood and Douglas fir was available for direct recruitment into the channel. This large woody material acted as an anchor for recruitment of smaller material such as alder, maple, and willow, the combination of which formed complex aquatic habitat. With anchor logs in place, pools could be scoured and sediment could be stored, attenuating its release downstream. These masses of woody material also created complexity in the channel through hydraulic variability that allowed for sorting of fine-grained material from gravel and cobble, a habitat building process that was beneficial to aquatic organisms including macroinvertebrates and salmonids. Wood generated habitat by scouring pools and building riffles.

What appears to be lacking in the Aptos Creek Watershed are large rootwads, which provide stable roughness elements and aid in the formation of deep pools. Compared to surveyed tributaries to the San Lorenzo, many of the reaches within the Aptos Creek Watershed contain about 1/3<sup>rd</sup> to 1/2 of the density of root wads. It is not clear what mechanism would be acting in the San Lorenzo River Watershed to retain rootwads compared to conditions in Aptos, but if restoration efforts are aimed at introducing additional woody material, it may be appropriate to focus on adding stable rootwads to encourage pool scour.

The survey results also suggest a clear difference between Aptos and Valencia in terms of the role woody material plays in creating habitat for salmonids. According to the data, Valencia and Aptos have comparable densities of woody material. If woody material was performing the same habitat forming function in both watersheds, we would expect to see similar numbers of pools being formed as a result of the presence of woody material. The results presented in Figure 20 suggest otherwise. Several dozen pools were formed in both Aptos and Bridge Creek as a direct result of the presence of woody material. This is especially true in the reach of Aptos Creek that is located just upstream of the Valencia confluence (Reach 2). Conversely, in Valencia Creek, no pools were observed to have been formed due to the


presence of woody material. We feel this is the direct result of the heavy sand load that is present in Valencia. Small pools may be forming during high flow winter months but are lost in summer as fine-grain sediment continues to be mobilized during the low flow months and settles out in the deeper, low velocity areas, ultimately filling the small pools.

Reach-ID	Diameter 1-2'				Diameter 2-3'				All Size Classes		
	# logs per mile (6-20')	# logs per mile (> 20')	Total logs per mile	Rootwads (# per mile)	# logs per mile (6-20')	# logs per mile (> 20')	Total logs per mile	Rootwads (# per mile)	Total logs per mile	Rootwads (# per mile)	Log Jams (# per mile)
A-1	3.2	0.0	3.2	3.2	0.0	0.0	0.0	0.0	3.2	3.2	0.0
A-2	37.7	19.2	10.4	57.0	7.4	6.7	6.7	14.1	75.5	21.5	0.7
A-3	27.9	25.3	3.2	53.2	6.3	5.7	6.3	12.0	70.9	12.7	2.5
A-4	22.9	30.6	0.0	53.5	5.6	8.1	2.5	13.8	69.8	8.1	0.0
A-5	34.2	33.1	2.9	67.3	6.8	12.0	0.6	18.8	89.6	5.1	0.6
A-6	26.6	15.3	0.7	41.8	8.6	6.6	2.0	15.3	63.7	5.3	4.0
B-1	55.6	44.1	1.6	99.7	10.6	9.8	9.0	20.4	128.3	13.1	4.1
V-1	21.7	16.0	4.7	37.7	9.4	2.8	4.7	12.3	55.6	11.3	0.0
V-2	28.5	21.0	1.3	49.5	10.9	3.8	3.4	14.7	67.6	8.4	3.4
V-3	30.9	26.9	5.7	57.8	11.4	2.9	3.4	14.3	77.2	14.9	0.6
T-1	28.6	12.8	3.0	41.4	9.0	3.8	7.5	12.8	60.2	16.6	2.3
M-1	14.5	3.6	0.0	18.2	0.0	3.6	0.0	3.6	25.5	0.0	10.9
Reach-ID	Diameter 3-4'				Diameter > 4'				Total Logs w/ Estimates from LDA's (# per mile)		
	# logs per mile (6-20')	# logs per mile (> 20')	Total logs per mile	Rootwads (# per mile)	# logs per mile (6-20')	# logs per mile (> 20')	Total logs per mile	Rootwads (# per mile)			
A-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2		
A-2	2.2	0.7	3.7	3.0	0.7	0.7	0.7	1.5	87.3		
A-3	2.5	1.9	2.5	4.4	0.6	0.6	0.6	1.3	88.6		
A-4	1.5	0.5	3.6	2.0	0.5	0.0	2.0	0.5	69.8		
A-5	0.6	2.3	1.1	2.9	0.0	0.6	0.6	0.6	103.9		
A-6	4.0	1.3	1.3	5.3	1.3	0.0	1.3	1.3	202.5		
B-1	4.9	2.5	2.5	7.4	0.0	0.8	0.0	0.8	291.7		
V-1	3.8	0.9	0.9	4.7	0.9	0.0	0.9	0.9	80.2		
V-2	0.8	1.7	2.1	2.5	0.0	0.8	1.7	0.8	122.5		
V-3	2.3	1.1	5.1	3.4	1.7	0.0	0.6	1.7	105.8		
T-1	3.8	0.8	3.0	4.5	1.5	0.0	3.0	1.5	79.7		
M-1	3.6	0.0	0.0	3.6	0.0	0.0	0.0	0.0	192.7		

**Table 10:** Results from woody material survey for anadromous reaches identified in the Aptos Creek watershed. The results are reported as # per mile. Results for reaches with a large number of log jams may be skewed since individual logs from the logjams were not included in the rest of the results.

## Legend

### Aptos Creek Watershed

 Rivers and Streams

### Large Woody Debris


# per Mile

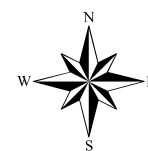
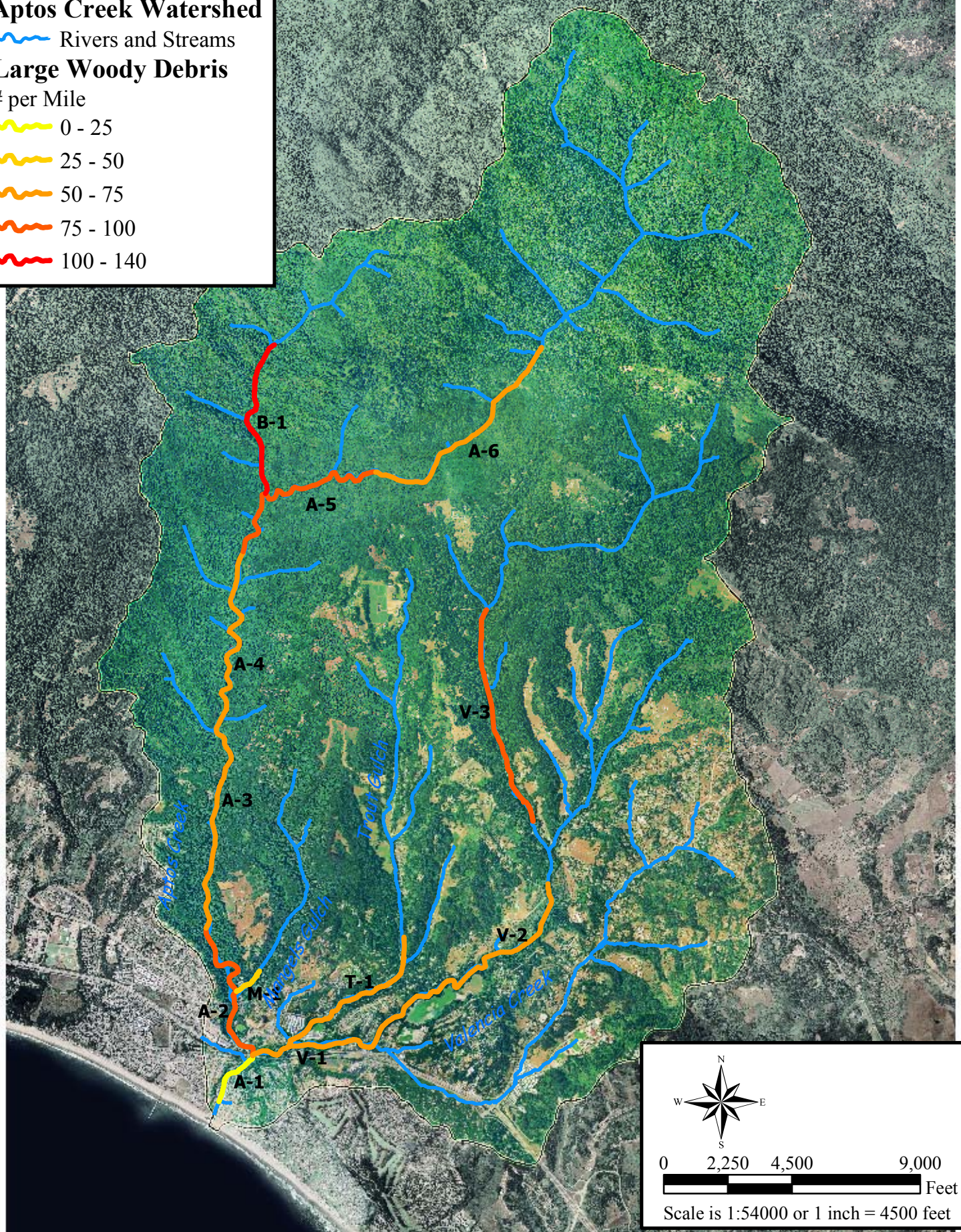
 0 - 25

 25 - 50

 50 - 75

 75 - 100

 100 - 140




0 2,250 4,500 9,000  
Feet

Scale is 1:54000 or 1 inch = 4500 feet

## Legend

### Aptos Creek Watershed

 Rivers and Streams

### Rootwads

# per Mile

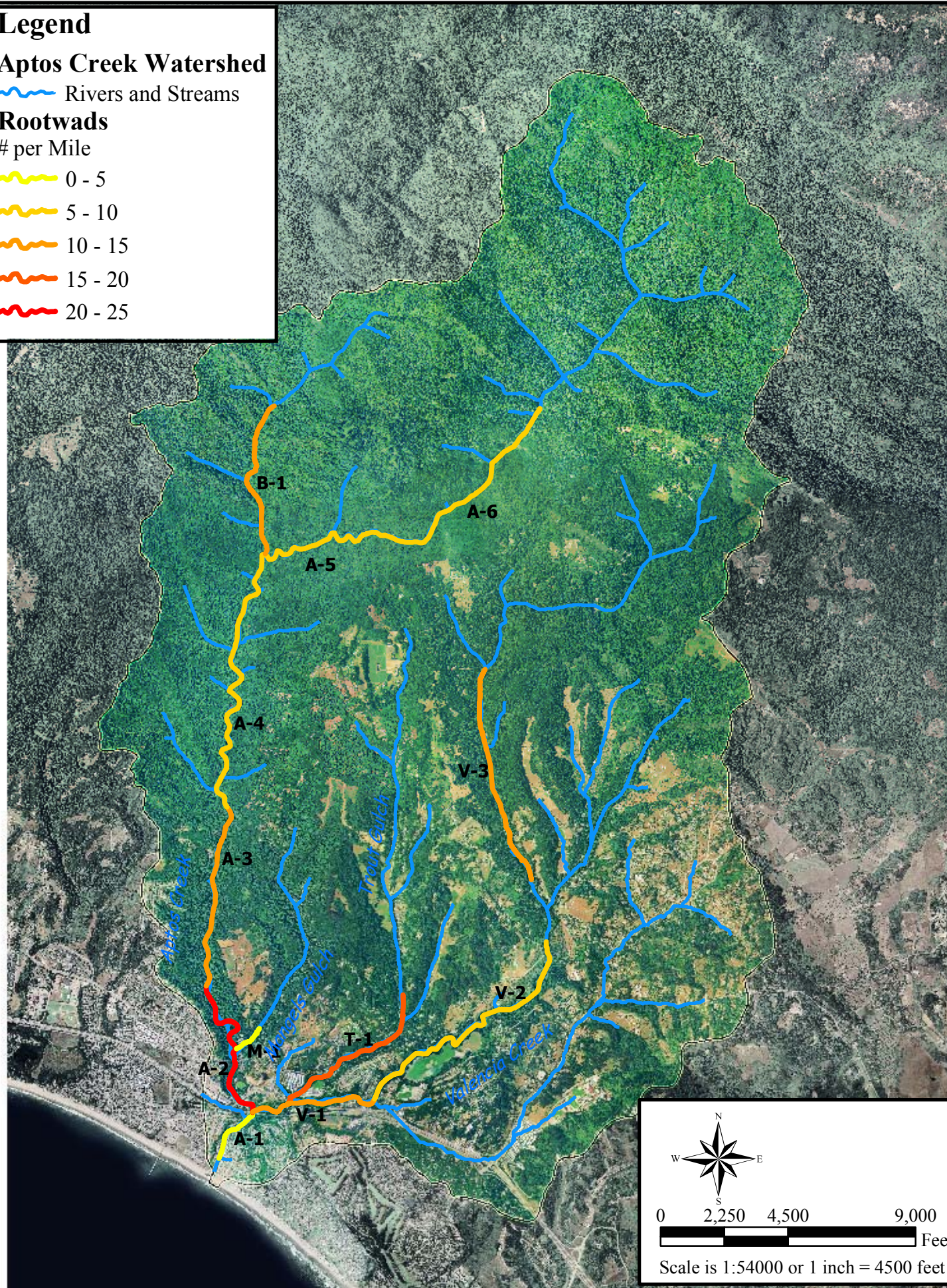
 0 - 5

 5 - 10

 10 - 15

 15 - 20

 20 - 25




0 2,250 4,500 9,000  
Feet

Scale is 1:54000 or 1 inch = 4500 feet

## Legend

### Aptos Creek Watershed

 Rivers and Streams

### Large Debris Accumulations

# per Mile

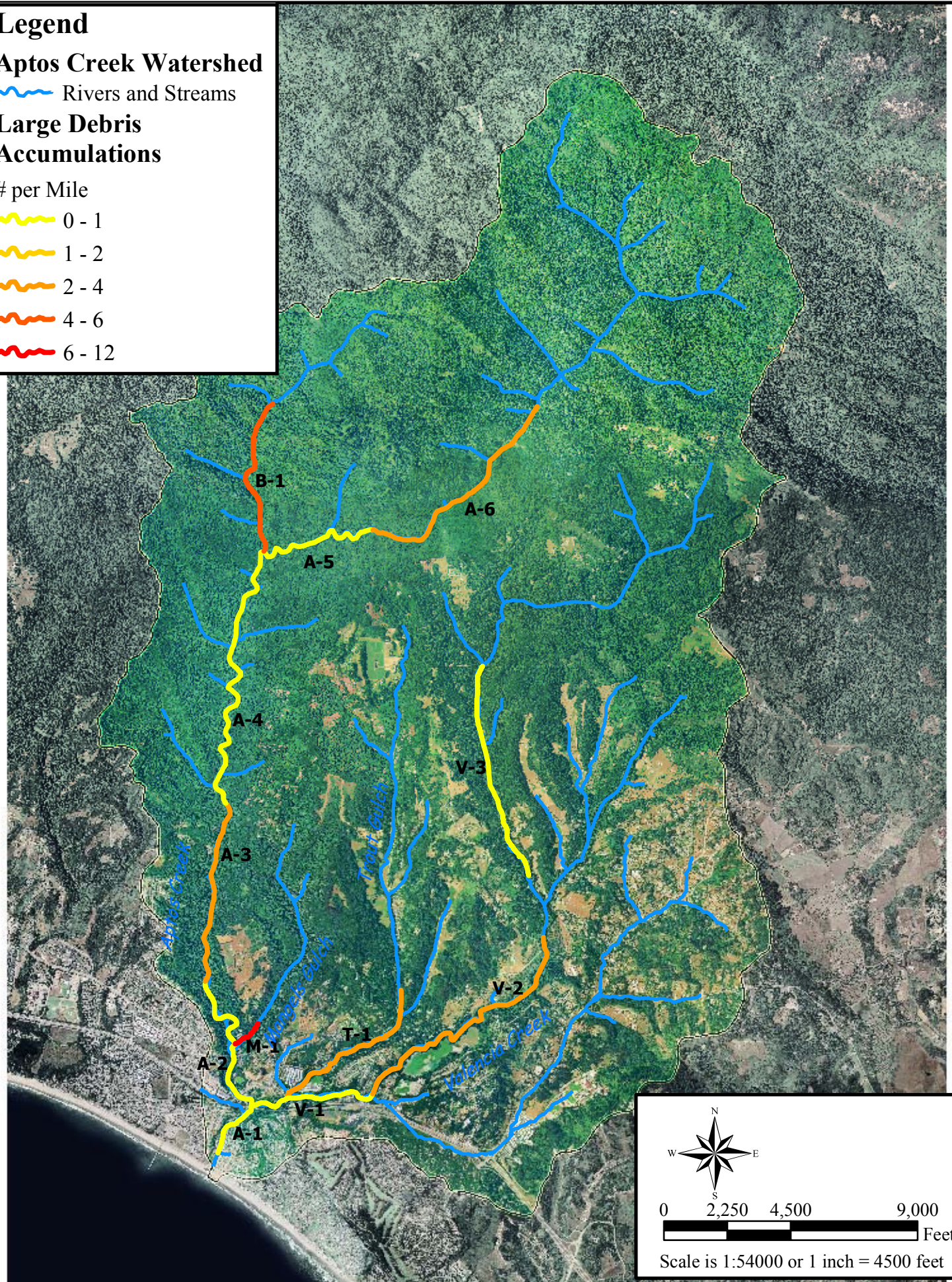
 0 - 1

 1 - 2

 2 - 4


 4 - 6

 6 - 12



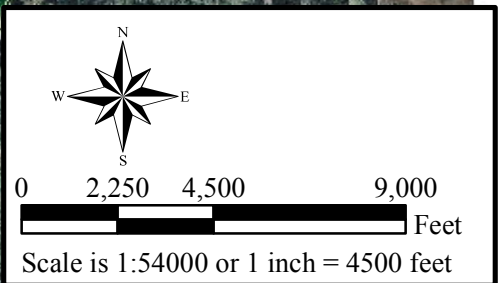
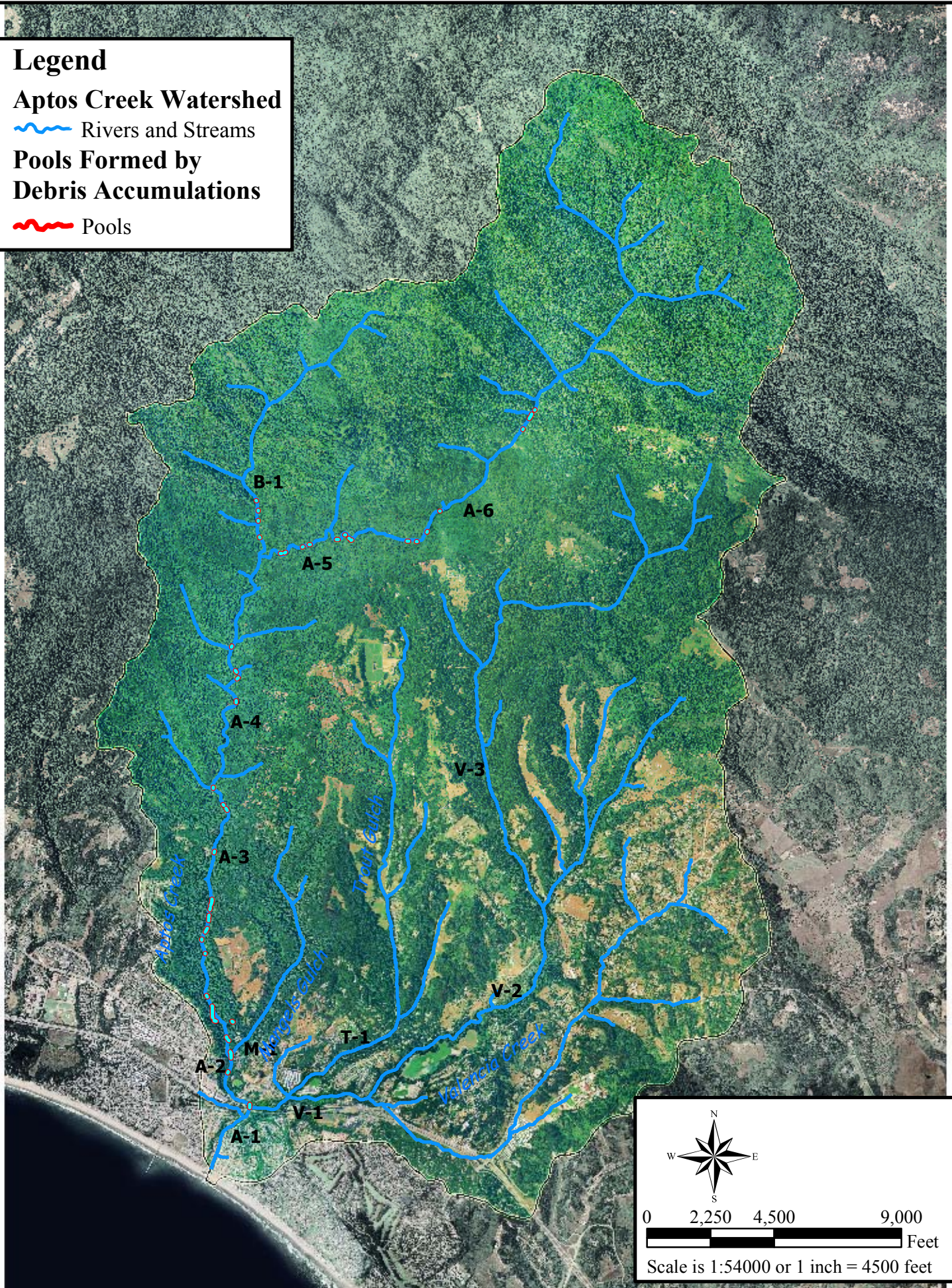
## Legend

### Aptos Creek Watershed

 Rivers and Streams

### Pools Formed by Debris Accumulations

 Pools





Examples of large woody material jams found in the upper watersheds of Aptos and Bridge Creeks. In the photo on the left, the jam appears to be associated with a shallow landslide. On the photo on the right, a narrow bedrock section backs up both wood and sediment, creating a potential fish barrier.

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## **APPENDIX A: LARGE WOODY MATERIAL INVENTORY DATA SHEET**

# L W D I N V E N T O R Y F O R M

Stream: \_\_\_\_\_ Sample \_\_\_\_\_ of \_\_\_\_\_ Reach No. \_\_\_\_\_

Date \_\_\_\_/\_\_\_\_/\_\_\_\_ Drainage: \_\_\_\_\_ USGS Quad: \_\_\_\_\_

Reference Point: \_\_\_\_\_ Sample Length (Ft) \_\_\_\_\_

Reach Location (Feet From Ref.Pt) Start \_\_\_\_\_ Stop \_\_\_\_\_ Total \_\_\_\_\_

Lat \_\_\_\_ N Long \_\_\_\_ W (Reach start or Ref.Pt.) T \_\_\_\_ R \_\_\_\_ S \_\_\_\_

Surveyors: \_\_\_\_\_

## CHANNEL CHARACTERISTICS (Attach Channel Typing Form)

Discharge Q \_\_\_\_\_ cfs Gradient \_\_\_\_\_ % Channel Type: \_\_\_\_\_

Percent Substrate in Boulders: (1' - 3') \_\_\_\_\_ %; (>3') \_\_\_\_\_ %

Air Temp \_\_\_\_\_ Water Temp \_\_\_\_\_

Right Bank						Stream			Left Bank					
% Slope _____ Dom. Veg. _____						Dom. Veg. _____			% Slope _____ Dom. Veg. _____					
	D/D	D/S	P e r	Live C D		Dead/ Down	D/S	Live C D	D/D	D/S	P e r	Live C D		
1-2d														
6-20														
Root														
1-2d														
>20'														
2-3d														
6-20														
Root														
2-3d														
>20'														
3-4d														
6-20														
Root														
3-4d														
>20'														
>4d														
6-20														
Root														
>4d														
>20'														

Note any LDAs (log jams), estimate size LxWxH and no. pieces. Note if gravel is retained upstream. Tally live conifer "C" and deciduous "D" trees separately. Tally root wads by diameter of "trunk". Include root wads <6' total length.

Comments:

## **APPENDIX B: PEBBLE COUNT SURVEY RESULTS**

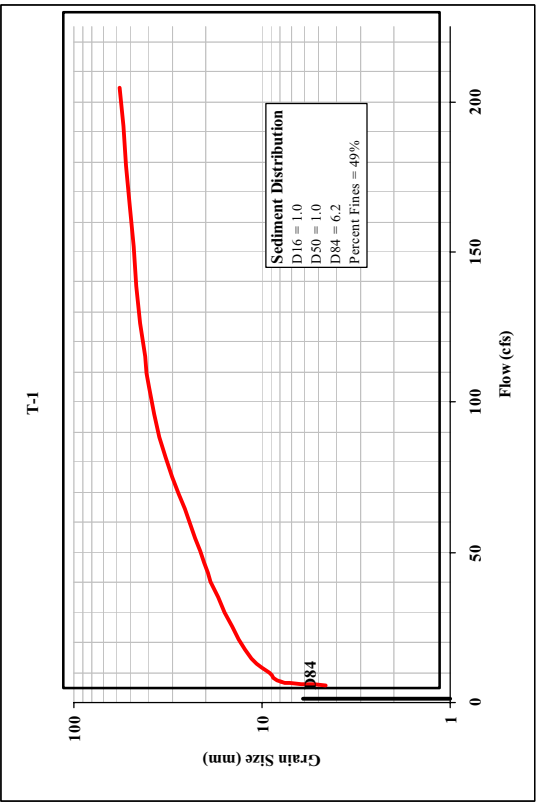
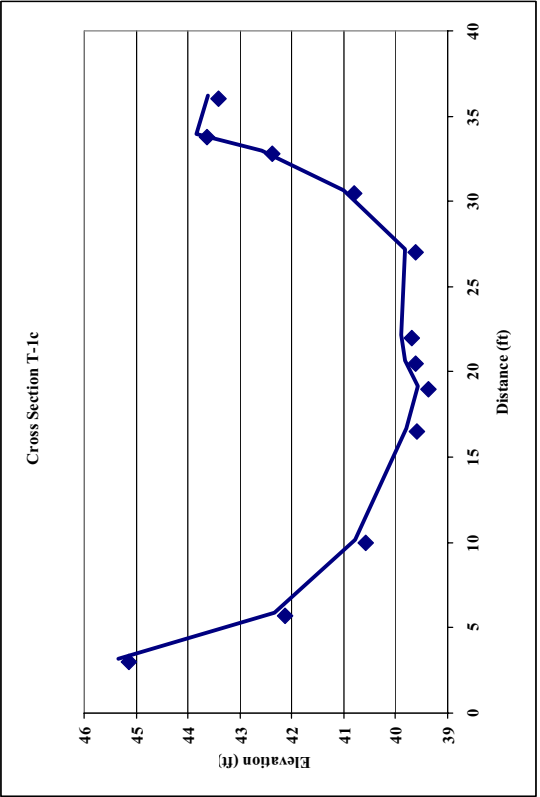
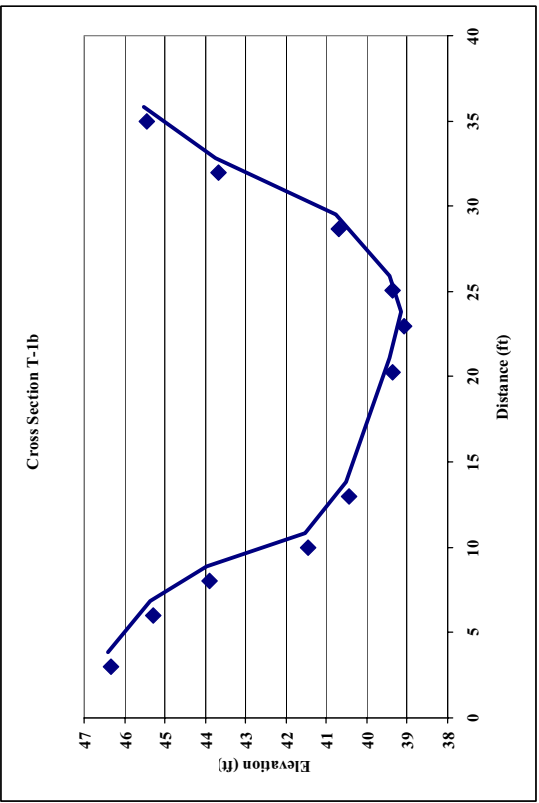
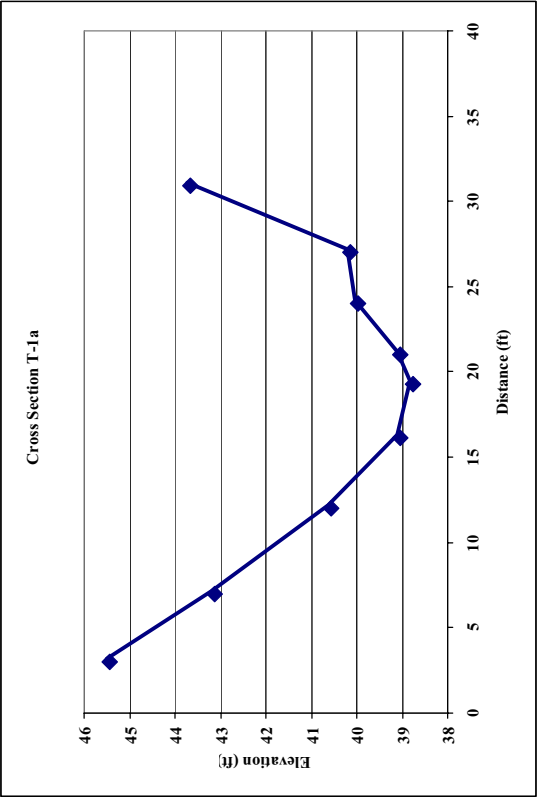


Figure B-1: Survey Site #1 in Trout Gulch. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.

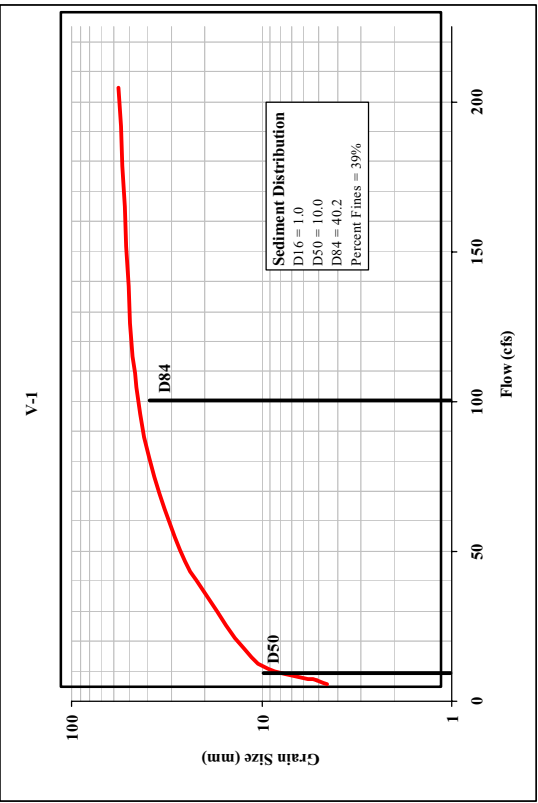
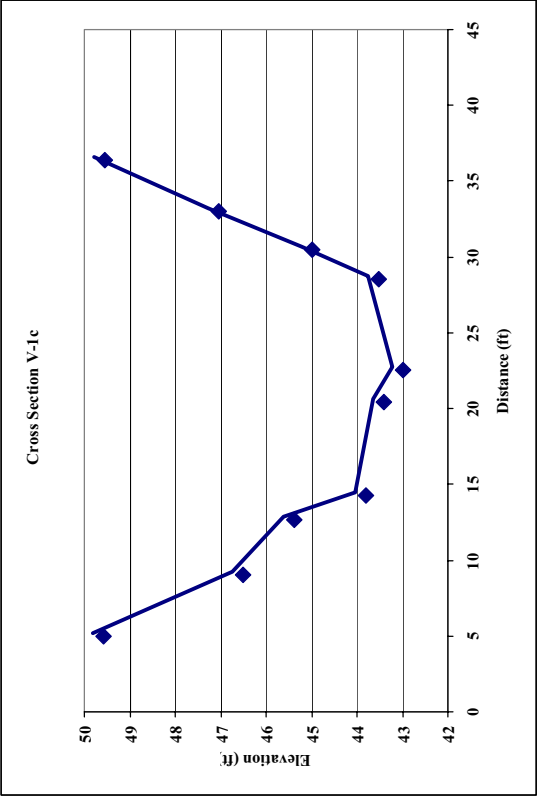
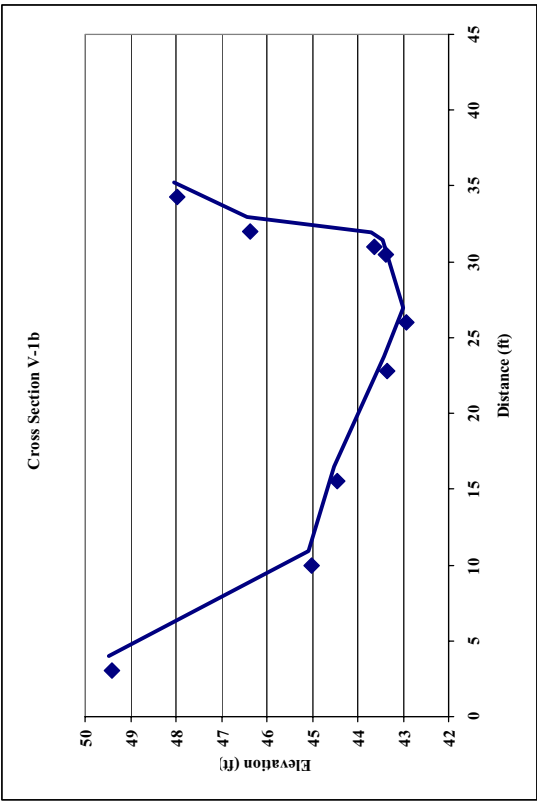
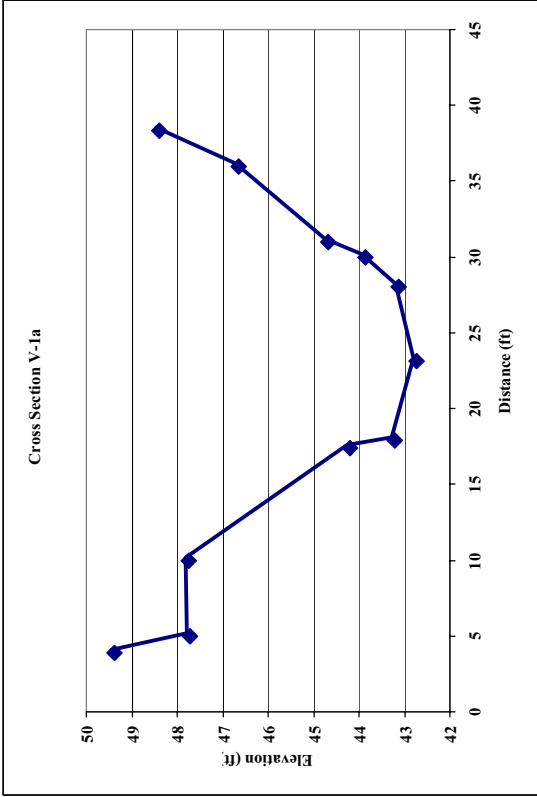


Figure B-2: Survey Site #1 in Valencia Creek. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.

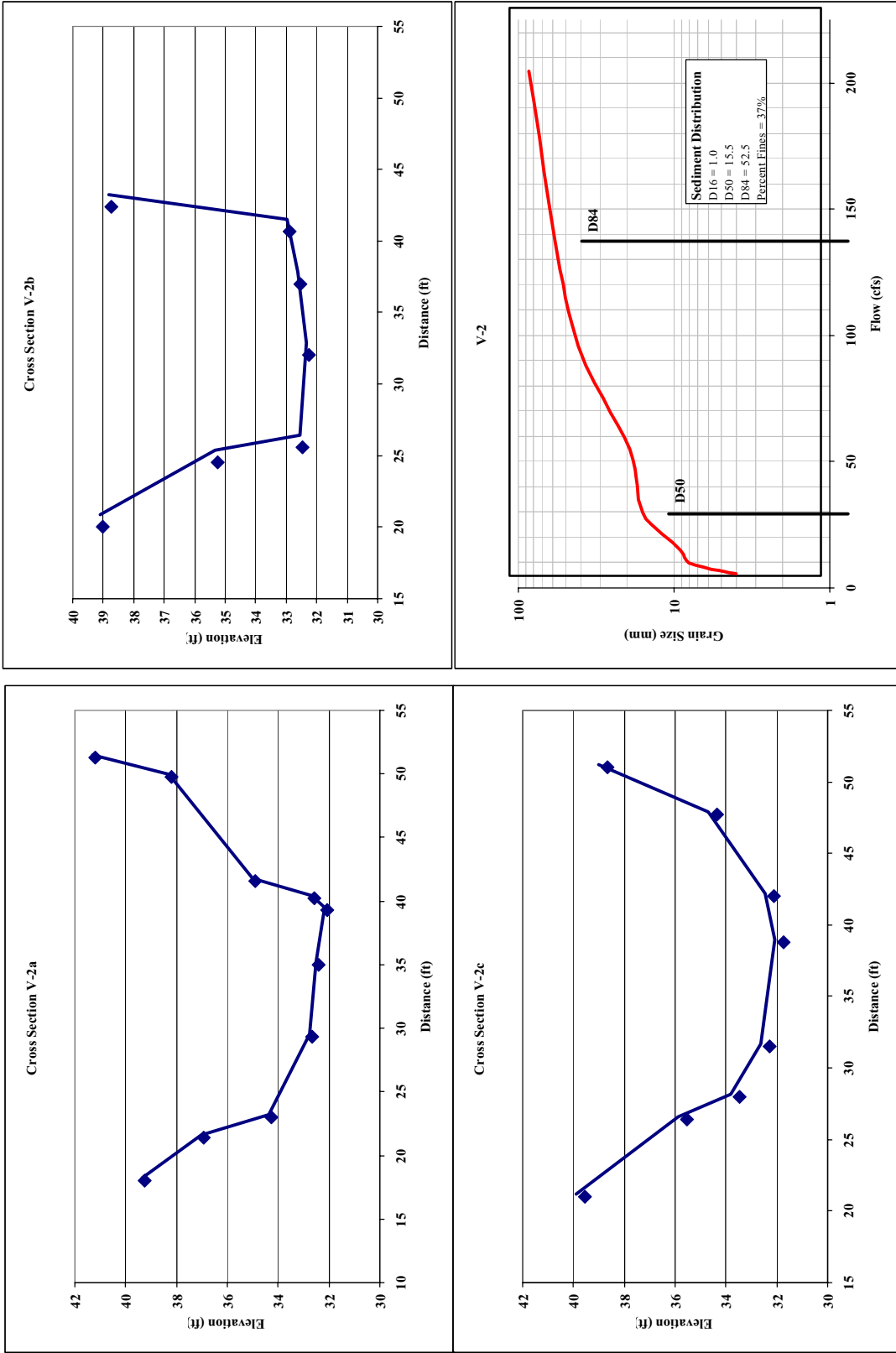


Figure B-3: Survey Site #2 in Valencia Creek. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.

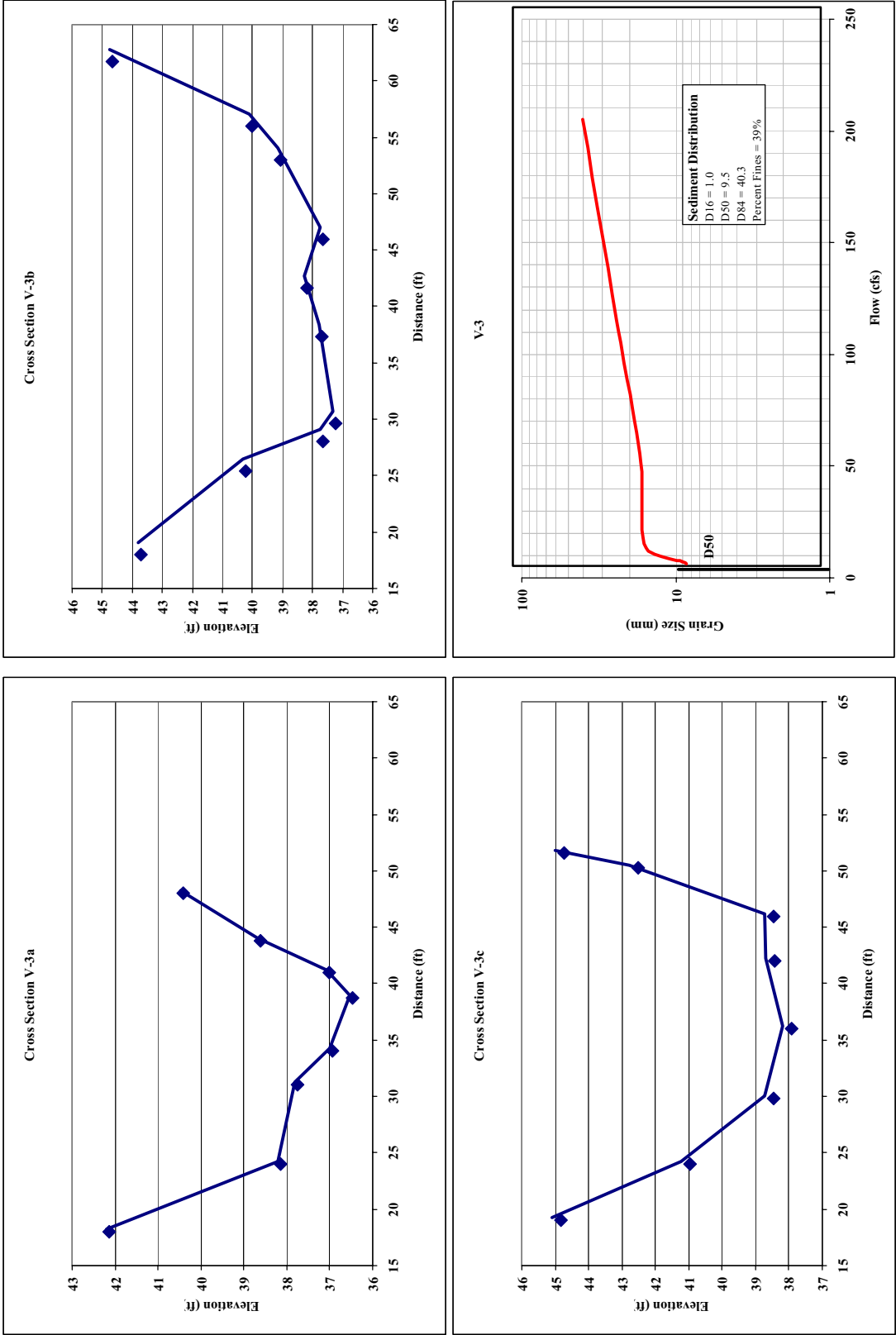


Figure B-4: Survey Site #3 in Valencia Creek. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.

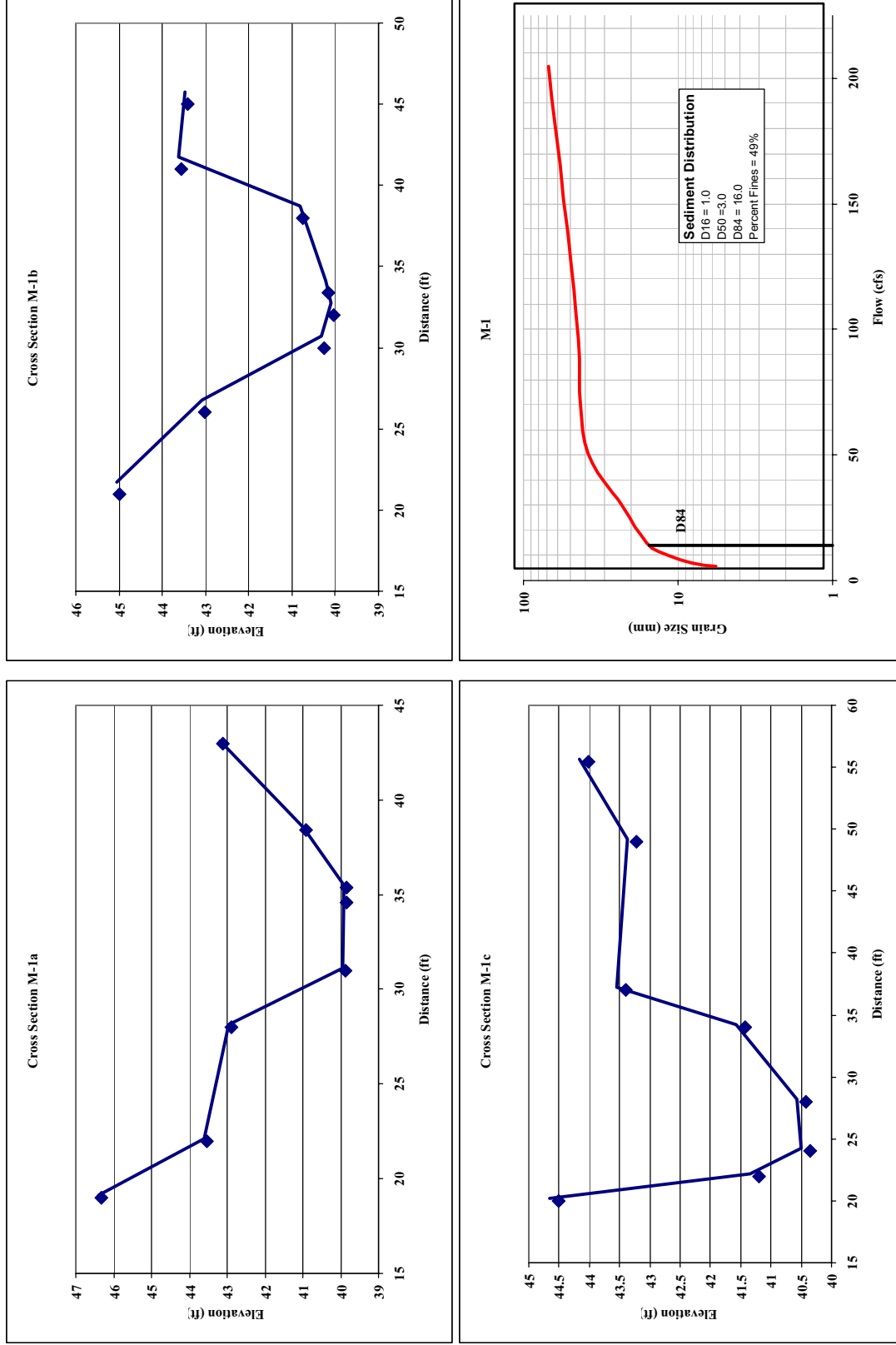


Figure B-5: Survey Site #1 in Mangels Gulch. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.

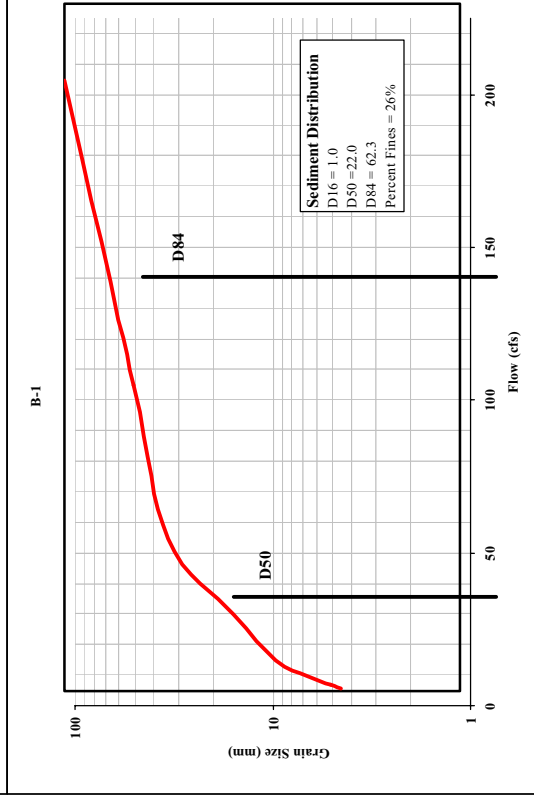
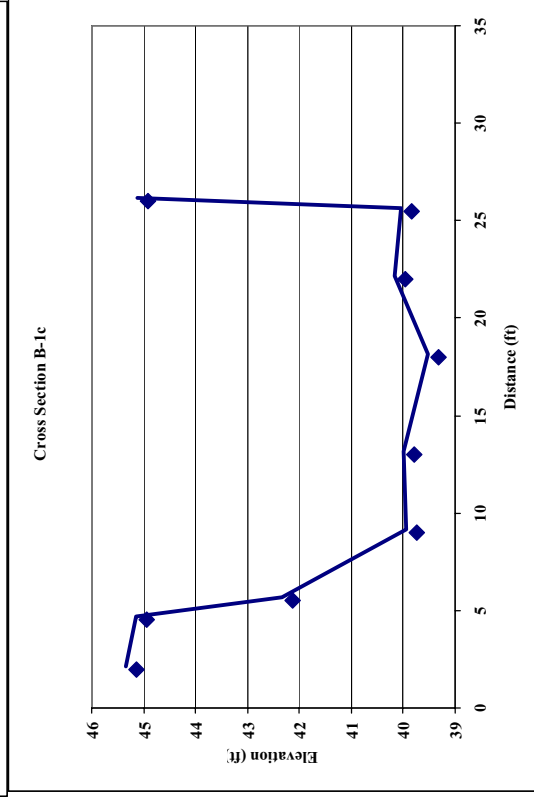
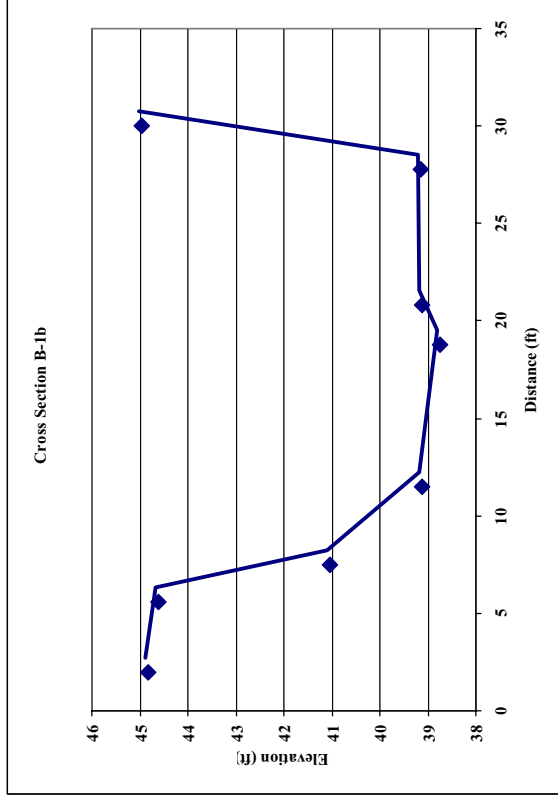
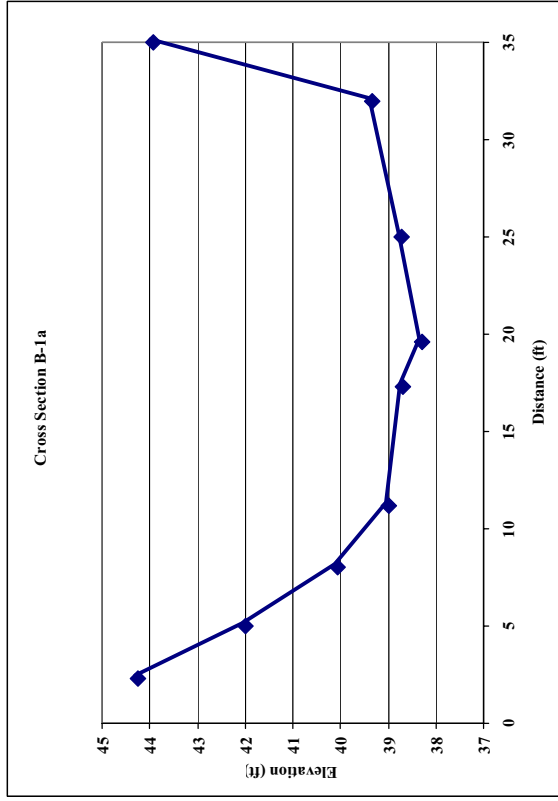


Figure B-6: Survey Site #1 in Bridge Creek. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.

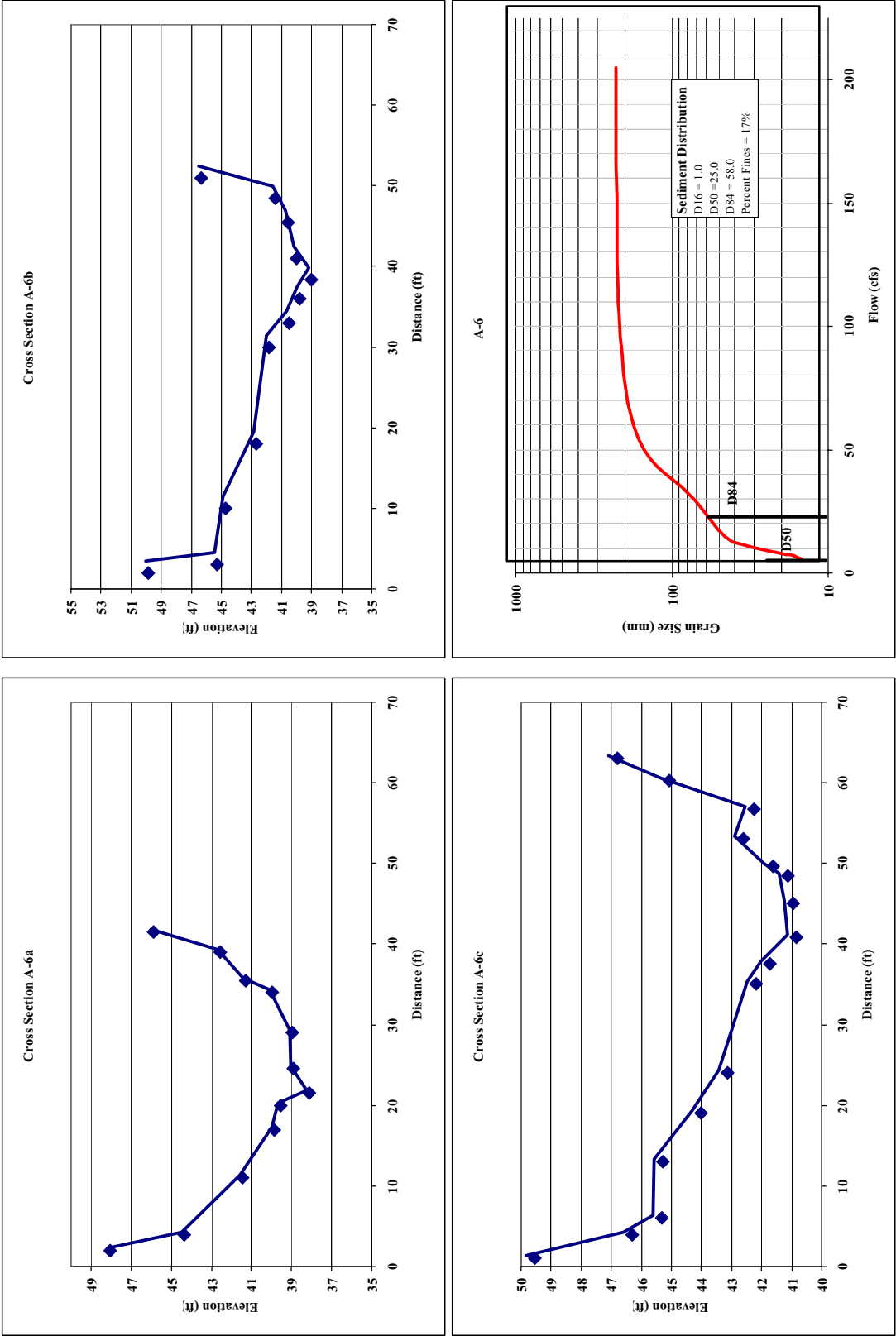


Figure B-7: Survey Site #6 in Aptos Creek. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.

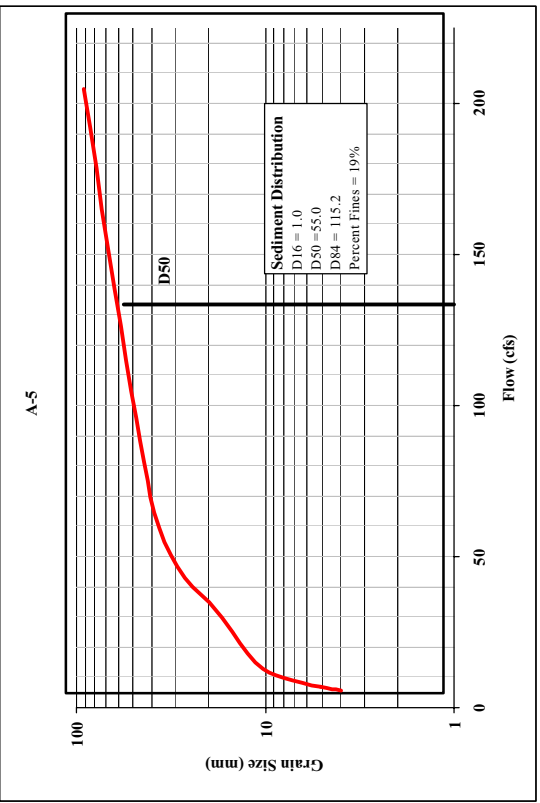
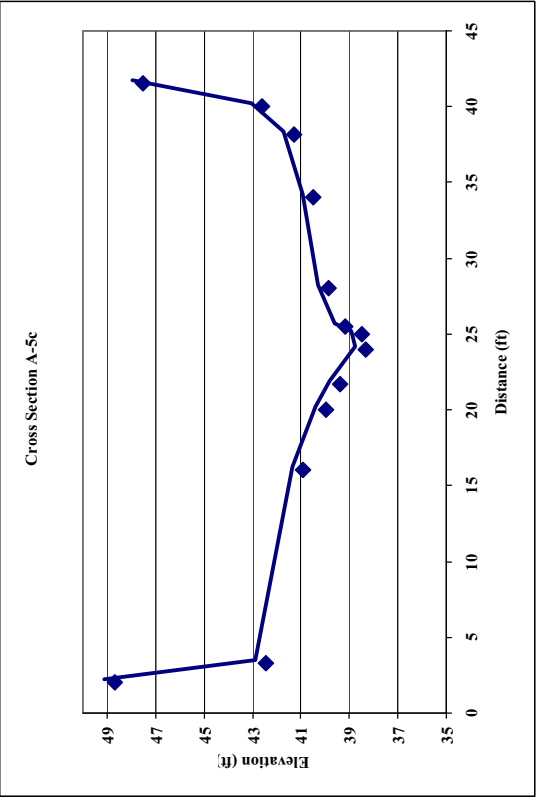
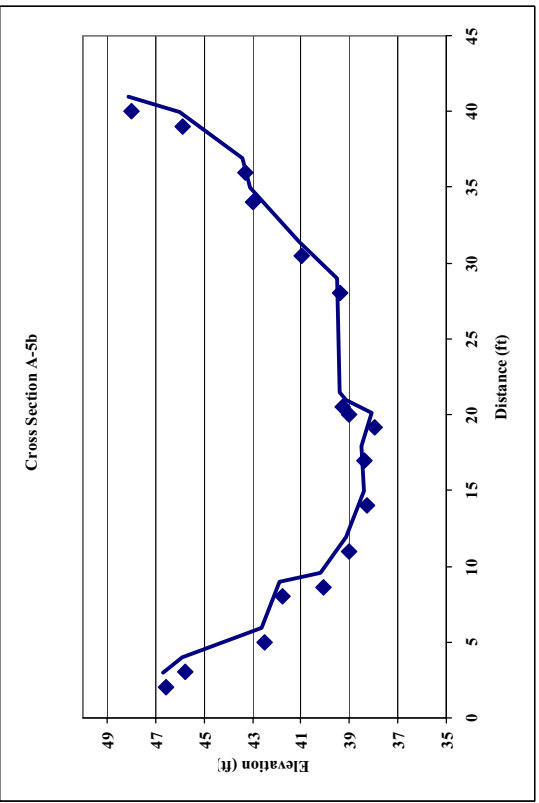
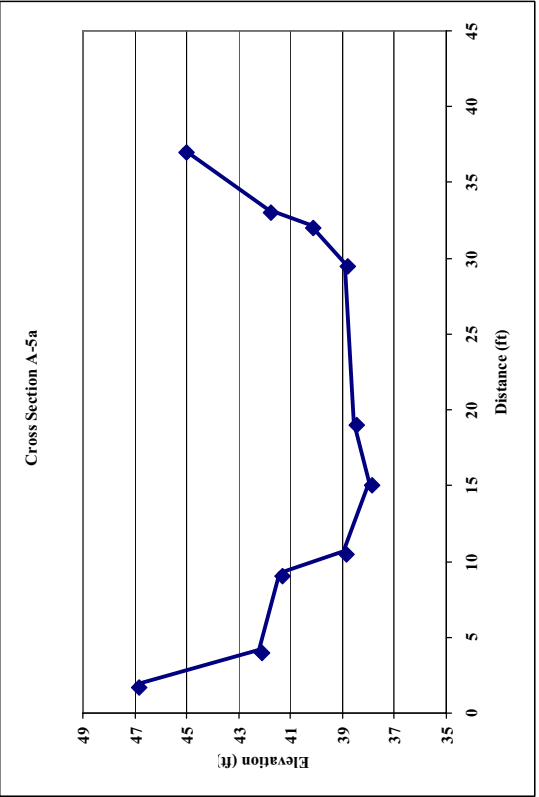


Figure B-8: Survey Site #5 in Aptos Creek. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.

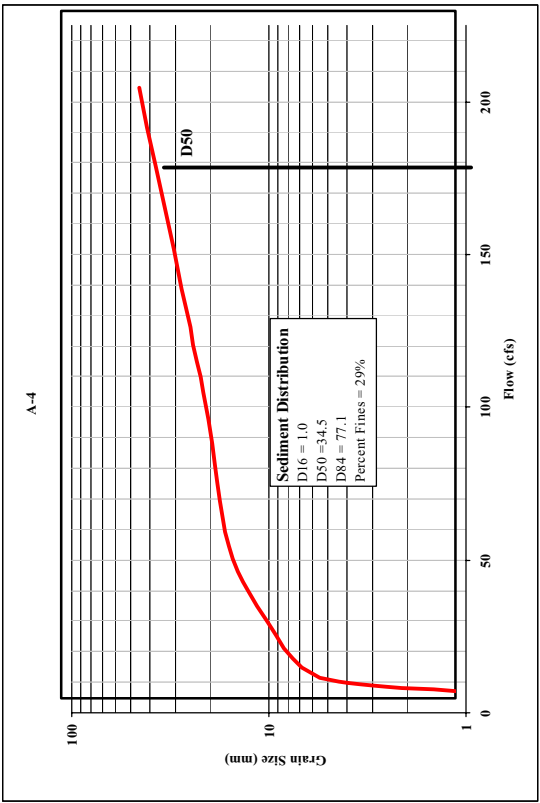
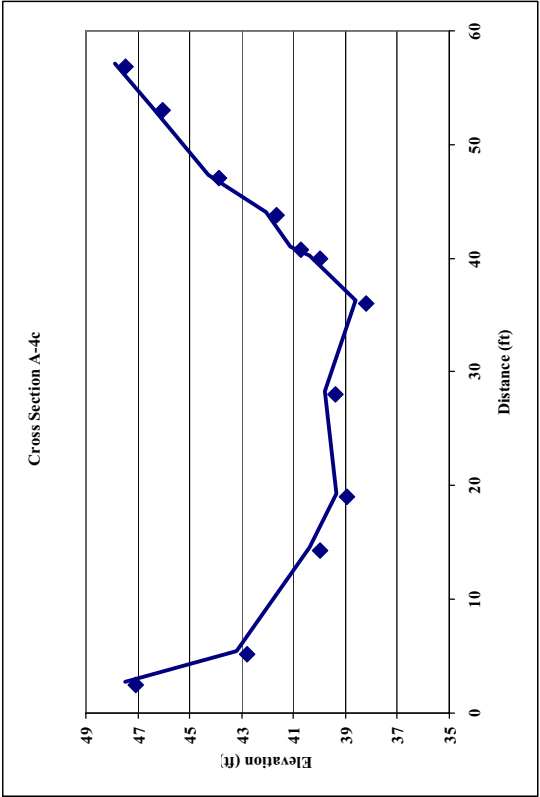
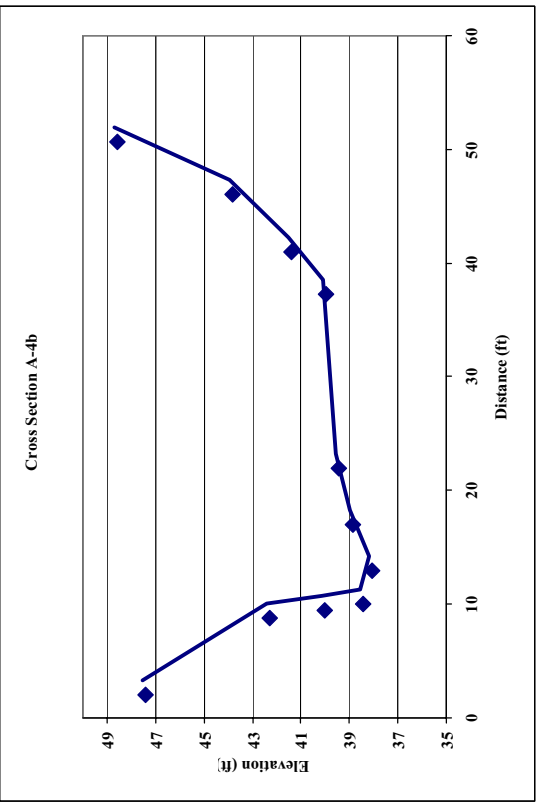
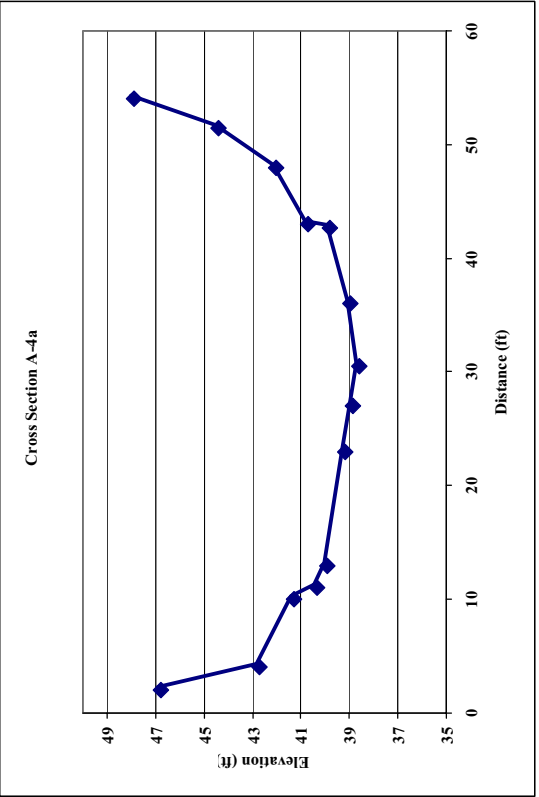


Figure B-9: Survey Site #4 in Aptos Creek. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.

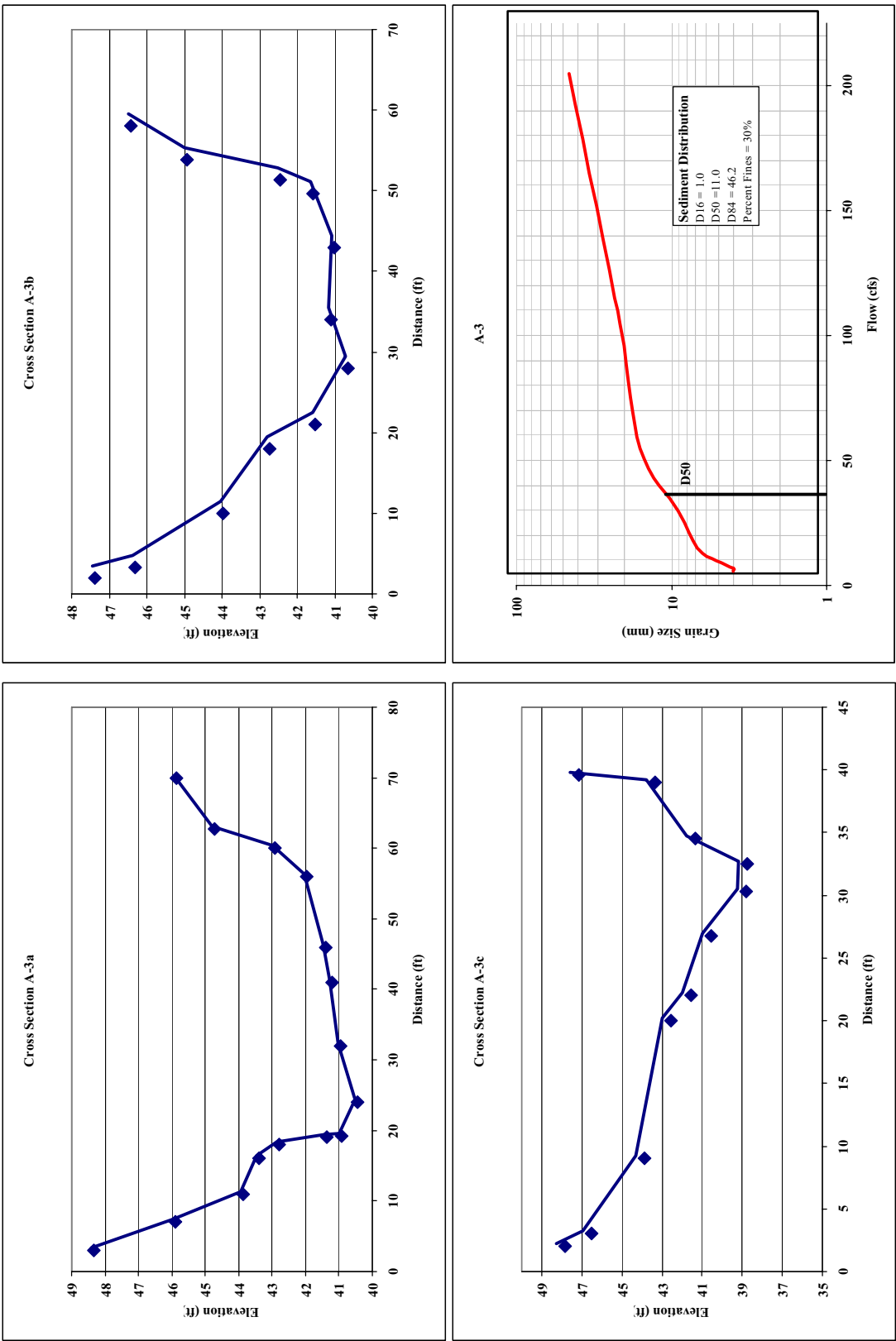


Figure B-10: Survey Site #3 in Aptos Creek. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.

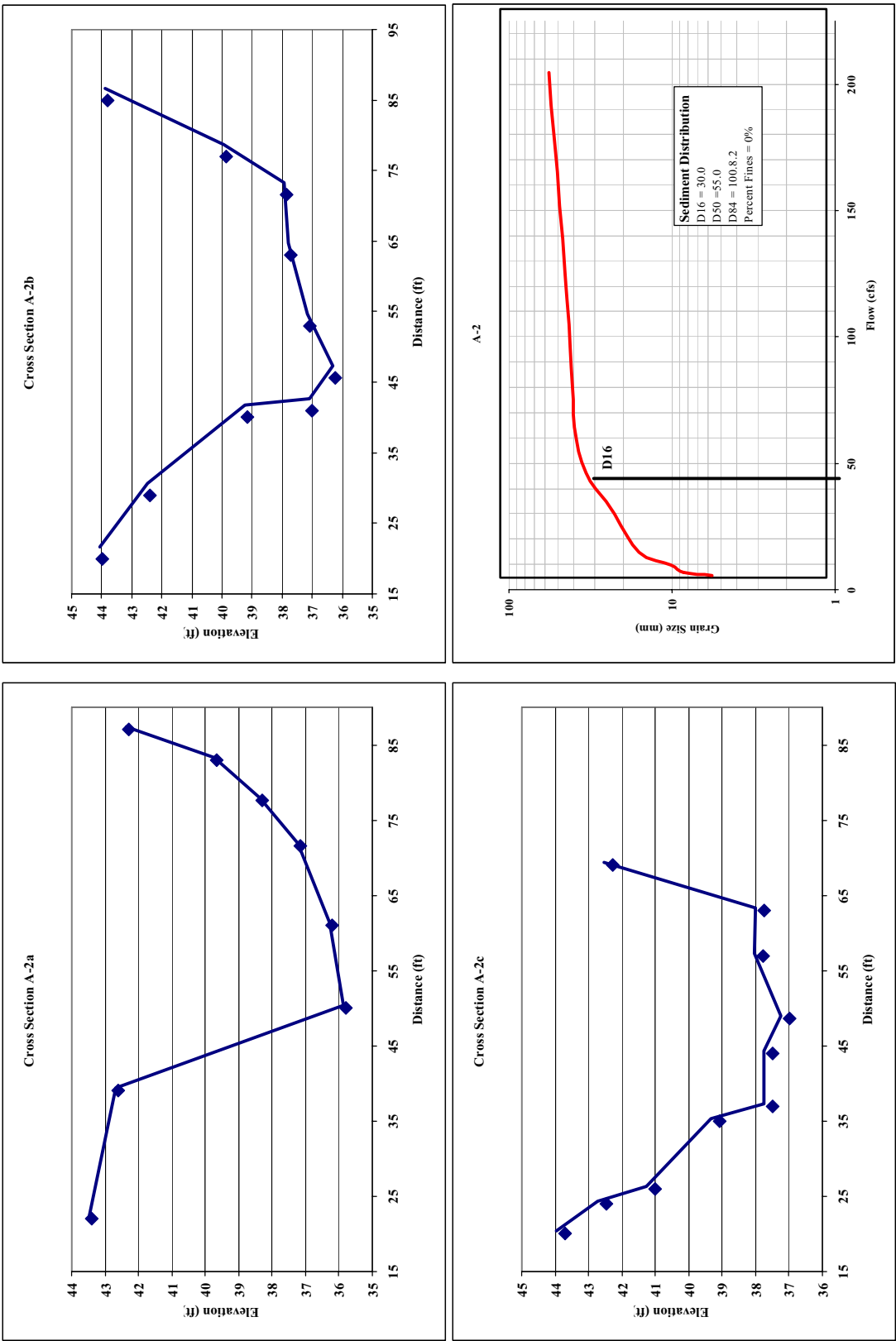


Figure B-11: Survey Site #2 in Aptos Creek. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.

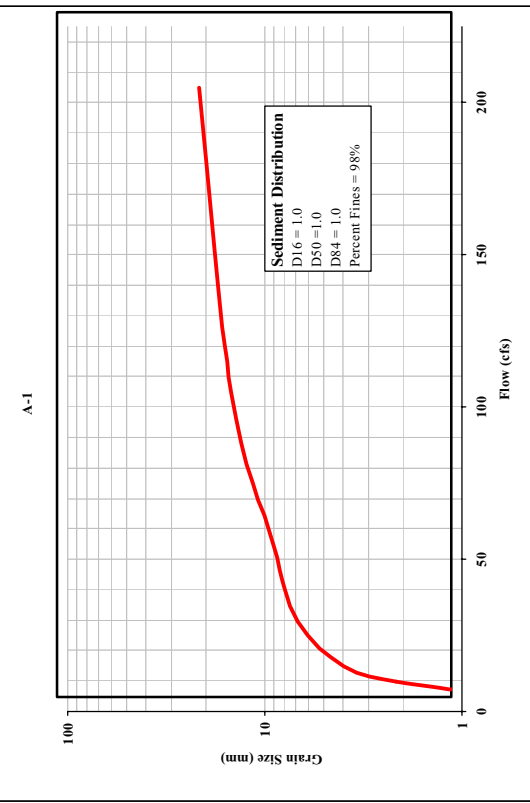
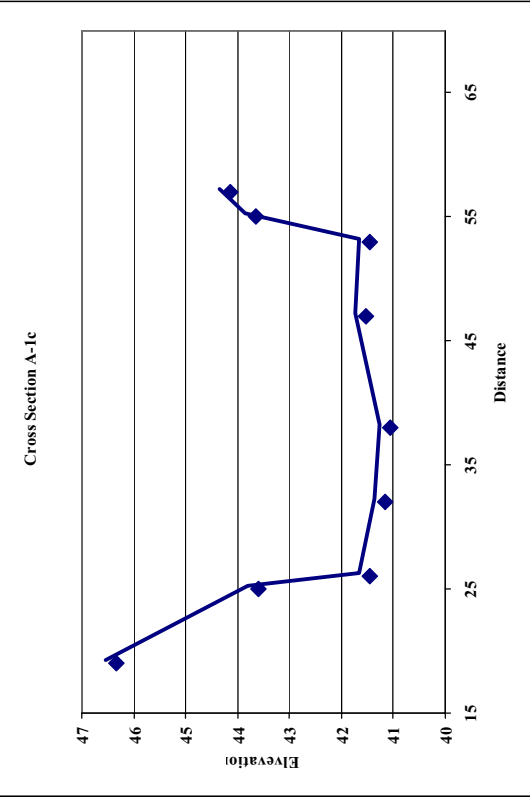
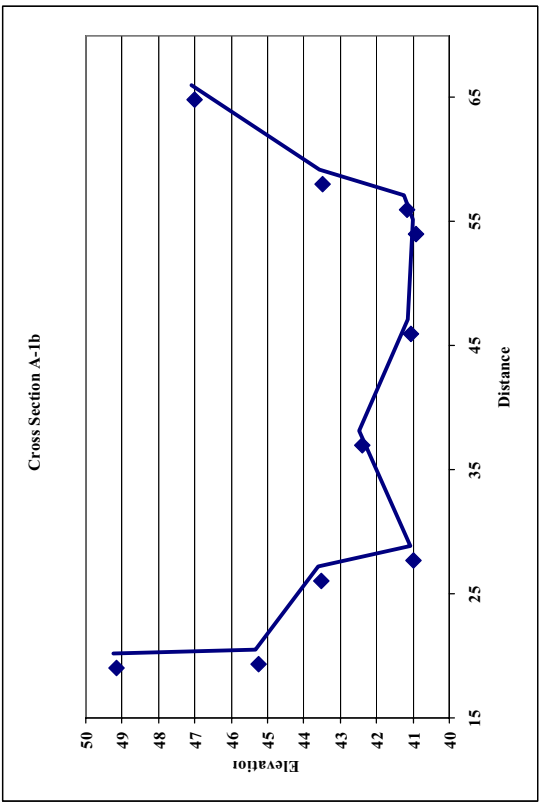
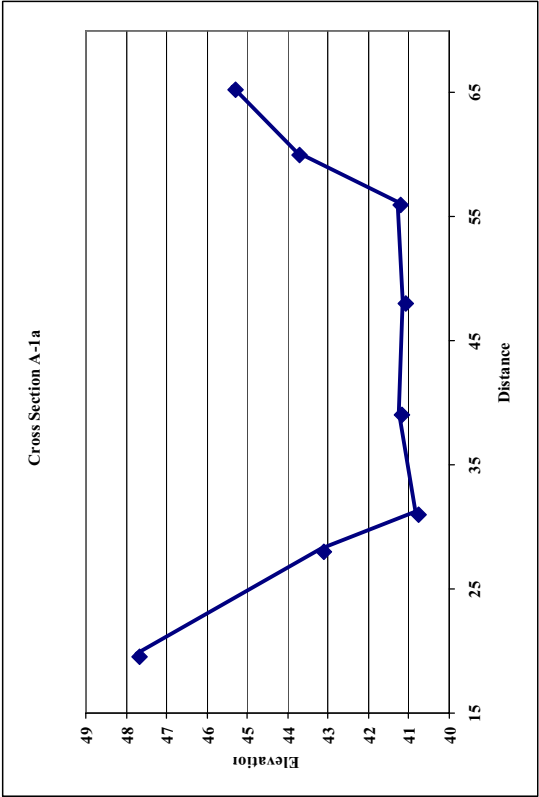


Figure B-12: Survey Site #1 in Aptos Creek. Cross sections developed through field surveys and used in HEC-Ras model to produce shear stress curve. D16, D50 and D84 developed from pebble count data collected on a depositional feature in the vicinity of the cross-section series. Elevations based on an arbitrary benchmark of 100 feet.